Appendix A: Population Viability Curves for Interior Columbia Chinook and Steelhead ESUs

Interior Columbia Basin Technical Recovery Team
March 14, 2007

Background

The Interior Columbia Technical Recovery Team (ICTRT) adapted a modeling approach for generating viability curves (McElhany et al. 2003) as a means of expressing the productivity and abundance component of population level viability criteria. A viability curve is defined by a set of paired combinations of productivity and abundance values corresponding to a particular extinction or quasi-extinction risk level. The ICTRT viability criterion for abundance and productivity requires a combination that addresses considerations for demographic persistence, the maintenance of genetic integrity and resilience to localized catastrophic risks.

We incorporate a minimum abundance threshold corresponding to the relative size category of the target population to address this range of objectives (Figure A-1). The standard time frame for assessing risk of extinction used in our analyses was 100 years. Each combination of productivity and abundance on a particular viability curve projects to the same modeled risk of extinction over a 100 year period.

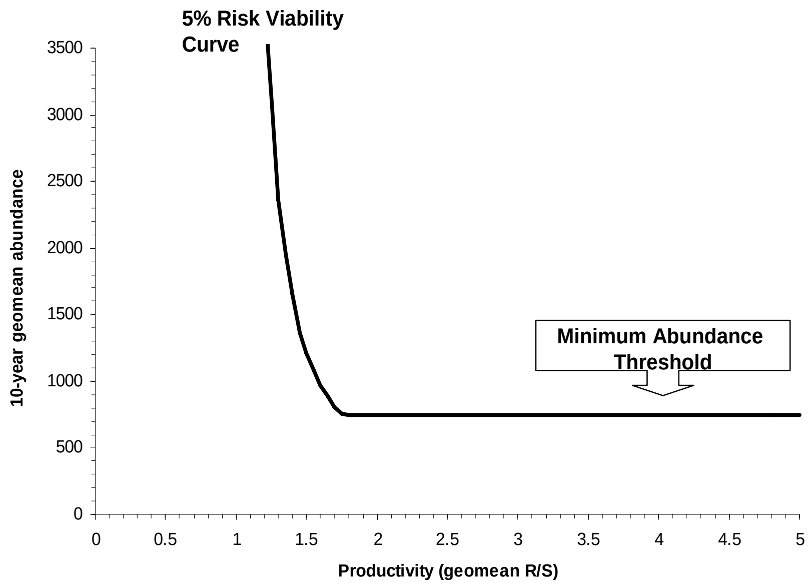


Figure A-1: Viability curve example. Curve represents combinations of abundance and productivity values associated with a 5% risk of extinction in 100 years, truncated to incorporate a minimum abundance threshold of 750.

The viability curve concept is adaptable, as the curves can be generated specific to a form of stock-recruit relationship and type of time series data available for a particular population or set of populations. In this example curve, abundance is expressed in terms of equilibrium spawning level and productivity as the expected geometric mean return per spawner at low to moderate abundance (the slope of the upward ascending limb of a Hockey-Stick function). In assessing the current status of a population against a viability curve, we recommend using a recent 10 year geomean of natural spawners as a measure of current abundance. Current intrinsic productivity should be estimated using spawner to spawner return pairs from low to moderate escapements over a recent 20 year period.

We developed two sets of ESU specific viability curves, each using a different measure of population growth rate. One set of curves expresses productivity in terms of return per spawner (to the spawning grounds). The alternative set of curves uses short term population growth rate (λ) as a measure of recent geomean productivity. The simple population growth rate based approach allows for assessments in circumstances in which the available data for assessing a population trend or abundance is limited and subject to high measurement error (Holmes, 2001). Fairly detailed annual spawner recruit data sets have been generated for most Interior Basin listed chinook populations and and many steelhead populations. Return per spawner based viability assessments can be directly adapted to accommodate large variation in annual abundance relative to potential capacity limitations as well as to autocorrelation in marine survival rates. We provide a detailed description of the derivation of the return per spawner based curves in the following sections, followed by a brief summary of adaptations of these basic steps to generate the population growth rate (λ) based viability curves.

In the following sections, we provide descriptions of the model we used to generate viability curves, descriptions of general and ESU specific input parameters, and a set of viability curves for each ESU. Representative estimates of year to year variability in return per spawner or population growth rates are key input parameters into the model used to generate population viability curves. We discuss key assumptions and uncertainties associated with curve generation and applications. We followed the basic approach for estimating variance and autocorrelation in production rates outlined in Morris & Doak (2002), adapting the approach to apply to time series of spawner to spawner return data sets.

We provide a brief summary of the use of viability curves in assessing current status. We used viability curves corresponding to a 25%, 5% and 1% risk of extinction in 100 years to define population level risks. Combinations of abundance and productivity falling below the 25% risk curve depicted in the chart (Fig. A-2) would be classified as at High risk. Combinations exceeding the 1% risk curve would be rated as at Very Low Risk. Abundance/productivity combinations falling between the 5% and 1% viability curves would be rated at Low Risk.

Under historical conditions, it is likely that most populations would have demonstrated combinations of intrinsic production potential and abundance well above the 5% Viability Curve. At the population level, recovery strategies should be targeted on achieving combinations of abundance and productivity above the threshold represented by the 5% viability curve. Estimates of current status will be based on sampling information and will therefore be influenced to some extent by sampling induced error and bias. We have provided some examples of approaches to directly incorporate provisions to minimize the potential for erroneously assigning a population to a relatively low risk status when the underlying risk may be high.

The last section of this attachment describes a sensitivity analysis of the effects on a curve of variations in each of the input parameters (variance and autocorrelation in productivity, age structure, and quasi-extinction threshold QET).

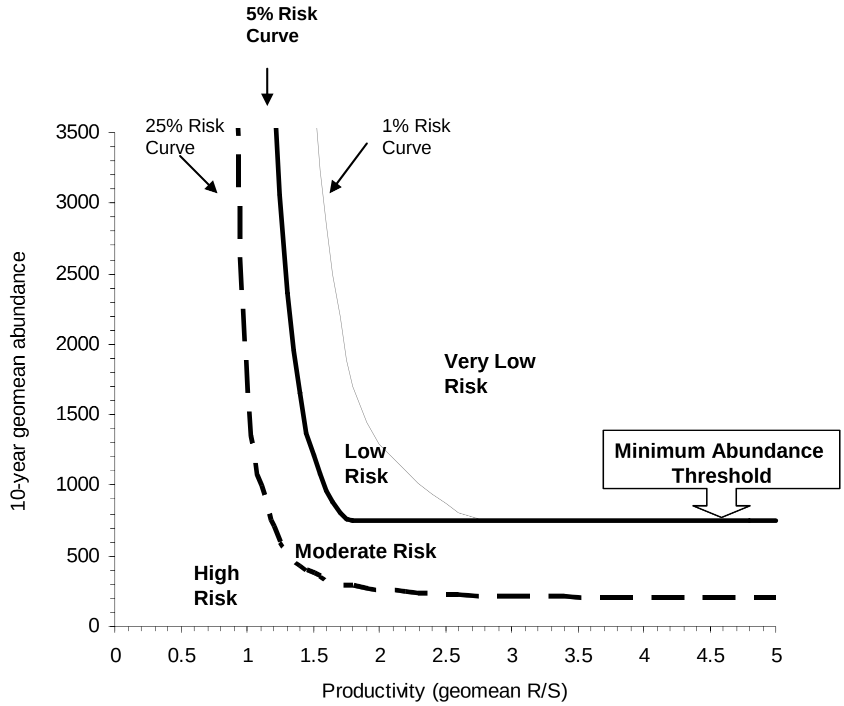


Figure A-2. Viability curve example. Curves represents combinations of abundance and productivity values associated with a 25%, 5% and 1% risk of extinction in 100 years, respectively. 5% and 1% curves truncated to incorporate a minimum abundance threshold of 750.

Viability Curve: Model Structure and Function

We used a stochastic cohort model to generate viability curves. The model generates a projected extinction risk given certain ESU-specific parameter estimates along with combinations of abundance and productivity. Additionally, the model includes an automated grid-search feature allowing the user to generate a viability curve corresponding to a selected risk level (e.g., 5% risk of extinction over a 100-year timeframe). We provide a detailed description of the mechanics of the model in this report.

The model operates on an annual time step. A model analysis consists of a minimum of 1000 iterations, each iteration being projected over at least 100 years. The cumulative results across the iterations are used to generate a probability of extinction corresponding to the input parameters for that analysis.

Stock-Recruit Function

The curves described in this report were generated using a hockey stick stock production function. We chose this function because it accommodates current status assessments based on simple measures of productivity at low abundance and production at capacity. It is also possible to express productivity and abundance/capacity in a viability curve in parameters in terms of the specific metrics in a particular stock-recruitment functions—e.g., Beverton Holt or Ricker curve a and b parameters. In most cases, data used to evaluate current status will be based on a relatively limited number of years. Uncertainty levels and bias in parameter estimates can be very large. Stock recruit function parameter estimates for relatively short data series that are based on fitting a standard function (e.g., Beverton Holt, Ricker or Hockey Stick) using a maximum likelihood or Bayesian fitting routine can contain substantial bias and/or uncertainty. These potential shortcomings are of less consequence if the available data series for a population is of sufficient length and/or if additional information is available to augment the trend data (e.g., environmental correlations, corresponding measures of juvenile production or smolt to adult survivals). Status assessments that use fitted stock recruit curve parameters as an index of current productivity should directly incorporate considerations for sampling induced errors and bias in their assessments.

Model Input Parameters

Two categories of input values are used in generating viability curves for application to Interior Columbia ESU populations. The first set included inputs that were common across all populations, regardless of ESU. Included in these generic inputs were the risk levels chosen for viability curves (e.g., 1%, 5%, and 25%) and the time period for assessing risk (100 years). This set also included values for extinction and reproductive failure thresholds as described below. The second set of parameters reflects characteristics of the specific populations within each ESU. Each population was assigned a minimum abundance threshold based on its estimated amount of historical spawning rearing habitat (see Attachment B). Population specific inputs included representative age at return proportions and a pair of parameters describing the expected variance and autocorrelation in annual return rates. The data sets used in generating population specific estimates of these parameters are included in population level current status assessments. Draft assessments are available at the ICTRT website. The ICTRT is developing an atlas of the current status assessments. That document will include a brief summary of regional methods for generating population specific estimates of annual abundance, age structure, etc.

Age at Return Distributions

We calculated average age distributions across available trend data sets for populations within each of the Interior Columbia listed salmonid ESUs. In some cases, population specific data sets were not available. If age composition estimates were available for aggregate returns including a population lacking a specific set of estimates, we assumed the aggregate estimate applied to that population.

Productivity: Variance and autocorrelation

One of our major objectives in this analysis was to identify variance and autocorrelation parameters representative of population productivity during rebuilding—a range that would include levels moderately above QET (50 spawners) to levels that would exceed the required equilibrium abundance thresholds specific to each population size category. We develop representative estimates of the variance and autocorrelation in annual return rate estimates for each of the listed Interior Columbia ESUs in this section. The estimates of annual variation in return rates were generated using population specific data sets and were averaged over a set of alternative stock-recruit functions (figure A-3).

Estimates for individual populations were based on relatively short data series subject to high levels of year to year variation. Therefore for those Interior Columbia ESUs represented by multiple populations (i.e., two stream type chinook and three steelhead ESUs), we averaged population level estimates of variance and autocorrelation across populations within ESUs to get representative sets of input parameters for generating viability curves. Population specific annual abundance data sets are described in Attachment B. We compiled brood year return estimates for the 20 most recent complete brood years for each data set.

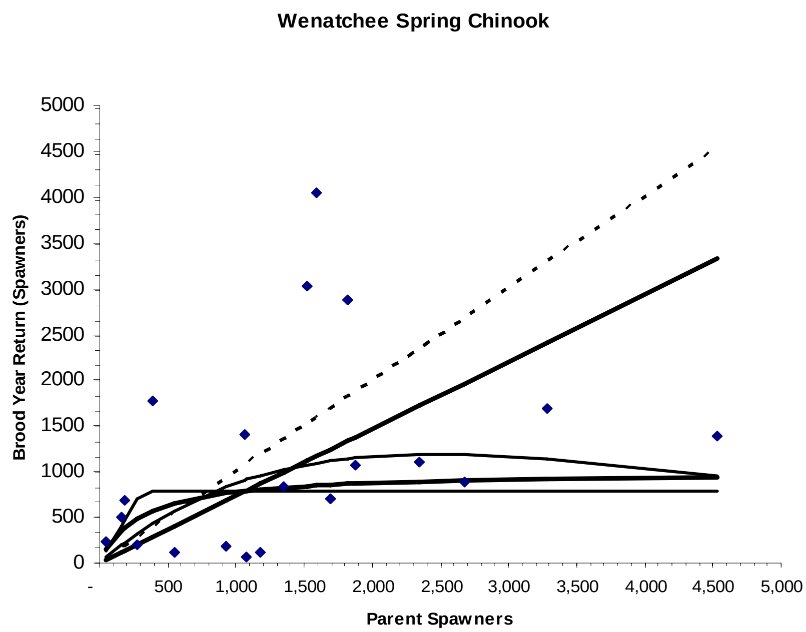


Figure A-3. Wenatchee River Spring chinook salmon population. Example of alternative stock-recruit functions (Random Walk, Hockey-Stick, Beverton/Holt and Ricker functions). Points are annual estimates of natural returns vs. total spawners in natural areas for brood years 1978 to 1999.

Differences in estimates between populations reflect the impacts of measurement error, departures from standard assumptions associated with fitting routines, etc. We considered a finer scale averaging (at the major population group level), but examination of the population level averages indicated more consistency at the ESU level.

We incorporated an autocorrelation parameter into the model used to generate viability curves based on results from our initial evaluation of representative trend data sets for Interior Columbia Basin Chinook and steelhead populations. We evaluated the time series of residuals from fitting a range potential stock recruit functions to the population specific data sets (Figure A-4). The annual residuals consistently demonstrated positive autocorrelation – that is, if the survival rate in a particular year was higher than average, there was a strong tendency for the survival in the following year to also be above average. Years that had relatively low survival rates tended to be followed by years with relatively low survival. The presence of autocorrelation in population growth rates can substantially influence projected extinction risks in population viability assessment models (Morris & Doak, 2002, Wichmann et al. 2005).

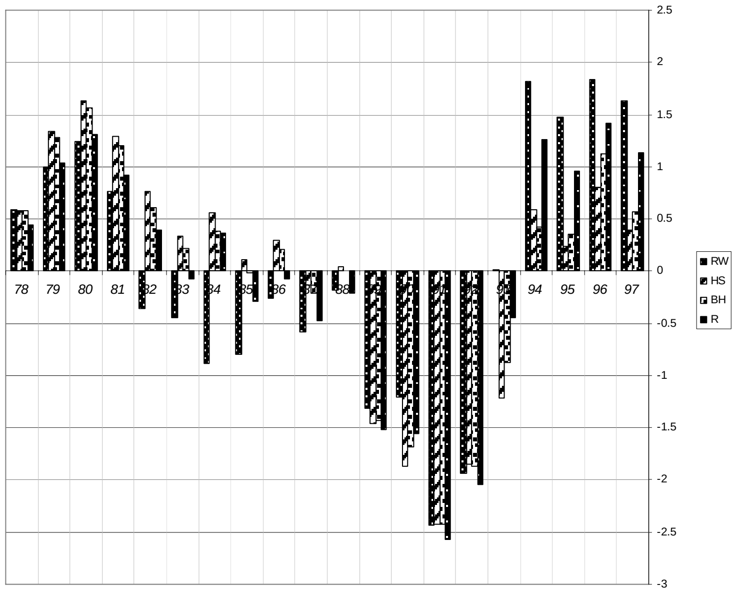


Figure A-4. Wenatchee River Spring Chinook salmon population. Deviations in annual return rates from predicted values using alternative stock/recruit functions.

We estimated simple one year lag correlation coefficients for the sequential series of residuals from fitting the basic stock-recruit functions to the individual trend data sets (Figure A-5). We limited our analysis to lag 1 correlations for several reasons: initial tests indicated lag 1 correlations were substantial and statistically significant; the data series we were evaluating were relatively short compared to the length required to estimate multiple year lag effects; and, incorporating lag 1 autocorrelation can effectively represent longer term cycles/patterns (e.g., Morris & Doaks, 2002).

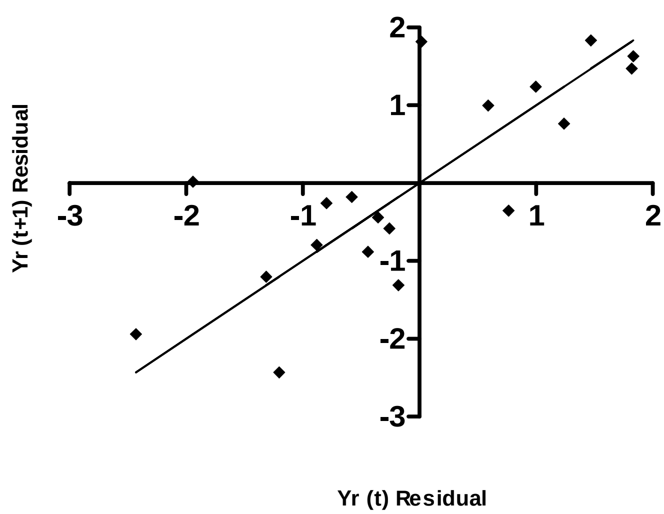


Figure A-5. Autocorrelation in annual variation in return rates. Wenatchee River Spring Chinook salmon population. Deviations in annual return rates from predicted values (Random Walk model). Points: year (t+1) vs. in year (t) residual deviations from predicted. Line represents 1:1 correspondence.

Quasi-Extinction Threshold

We evaluated model projections against a quasi-extinction threshold (QET) of 50 adult spawners per year over four consecutive years (generally corresponding to a brood cycle). A quasi-extinction threshold is defined as " ..the minimum number of individuals (often females) below which the population is likely to be critically and immediately imperiled." (Morris & Doaks, 2002; Ginsburg et al. 1982). We selected 50 as a QET based on four considerations; consistency with theoretical analyses of increasing demographic risks at low abundance, uncertainty regarding low abundance productivity of Interior Columbia ESU populations due to the paucity of escapements less than 50 spawners in the historical record, sensitivity analyses indicating that the probability of multiple very low escapements increases substantially as the QET approaches 1 spawner per year, and consistency with applications by the Puget Sound and the Lower Columbia/Willamette TRTs (McElhany et al. 2003, 2006; Puget Sound TRT, 200). We further discuss each of the rationale in the Population Abundance and Productivity section of our report on viability criteria (ICTRT, 2007).

Reproductive Failure Threshold

The QET is specifically expressed in terms of abundance over a four-year brood cycle. We also applied a Reproductive Failure Threshold (RFT) at the annual escapement time step in our model. In a given spawning year, production from an extremely low number of spawners are subject to decreases in reproductive success due to factors such as inability to find mates, random demographic effects, etc. In our viability modeling, we set production from a particular spawning year to zero if the adult escapement for that year was below the RFT. Initially, we set the RFT at the same value (on a per year basis) used in establishing a Quasi-extinction threshold (QET)—50 spawners. However, we have revised our estimate of the RFT appropriate for application to yearling type chinook and steelhead population model runs to 10 spawners after reviewing updated run reconstruction data sets for Interior Basins Spring/Summer Chinook populations and considering the potential for increases in sampling bias and heightened demographic risks as a function of extremely low abundance levels. We developed two simple analyses to inform setting the RFT at a number appropriate for Interior Basin chinook and steelhead populations. One analysis focused on the relative impact of sampling bias at low escapement levels, the other on a simplified model of demographic risk as a function of low escapements and multiple spawning sites.

Low Abundance Sampling Bias

Sampling related errors can substantially increase bias and variability in estimates of productivity derived for low spawning escapement levels. Our estimates of current intrinsic productivities for Interior Columbia Basin populations are based on annual population abundance data series. Natural returns are broken down into age components by applying a sampling based year specific age composition or an average age composition representative of the population. Year specific productivity estimates are then calculated by summing the returns by age corresponding to a particular brood year and dividing by the total parent escapement. Productivity estimates for extremely low spawning escapements in the data series can be biased upwards by sampling induced errors.

Annual spawner estimates for Interior Columbia Basin yearling type chinook populations are based on redd counts. At very low spawning levels, a single redd represents a substantial proportion of the total return. Annual return per spawner estimates are generated by total estimated returns at age for a given brood year by the parent spawning escapement in that brood year. Missing one or more additional redds at estimated total return levels of 2 to 10 spawners can result in substantial overestimates of spawner return rates.

Year to year variations in estimated spawning abundance is high. We developed a simple example of the potential impact on estimated productivity of year to year variability in abundance and the use of an average age composition to estimate brood year returns. The objective of the exercise was to evaluate the potential for bias in estimating productivity levels associated with extremely low spawning escapements (less than 100 spawners). We incorporated data from Interior Columbia Basin population abundance series into the assessment.

We averaged the relative ratios of low escapement year returns to returns in adjacent years across time series for Interior Columbia Basin population data sets. As an example, the estimated number of spawners in the Bear Valley population of spring/summer Chinook was 16 in 1995. The numbers of spawners estimated for 1994 and 1996 were 56 and 32, respectively. The ratios of the number of spawners in 1994 and 1996 to the estimate for 1995 were 3.5:1 and 2:1, averaging 2.8:1. We ordered spawning escapements and their relative ratios against adjoining return years and calculated median ratios across increments of 10 spawners (Figure A-6).

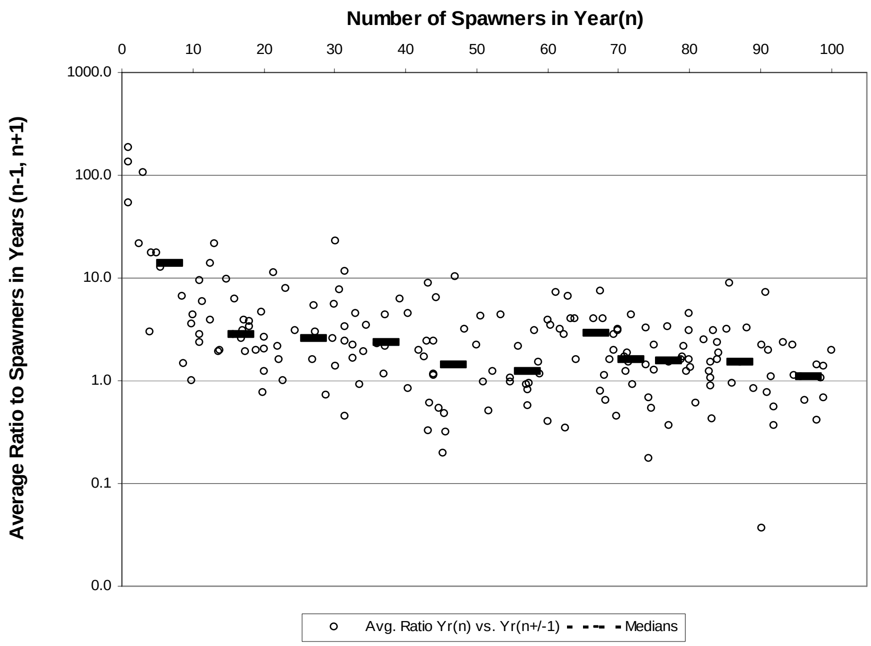


Figure A-6. Average ratios of spawner numbers in year$_n$ to spawner numbers in years$_{n\pm1}$ from Interior Columbia Basin population specific data sets. Ordered by the number of spawners in year$_n$.

Most of the low return levels in the data series were from relatively small populations in the Snake River Spring/summer ESU. For those series, the age information used to allocate natural returns to brood years with low parent escapement levels was an average for the population. For this exercise, we assumed an average age composition of 0.50 age 4 and 0.50 age 5 fish. A simple example will illustrate the level of bias in estimating productivity at low escapements that can arise from the combination of high variability in annual return rates and using average age composition data. Assume that a population data series includes a sequence of 100, 8 and 100 spawners in years 0, 1, and 2 and that the productivity for each of these years is 1.0. Equal proportions of the production from each brood year return at ages 4 and 5. In this scenario, 54 spawners would return in years 4 and 5. Applying the average age structure to year 4, an equal number of spawners (27) would be allocated to brood year 0 and to brood year 1. In this example, the same number of spawners (27) would be estimated as 5 year old spawners in year 6 and allocated to brood year 1. The total estimated returns from brood year 1 would be 55. The productivity from the escapement of 8 spawners in brood year 1 would be calculated as 55 divided by 8, or 6.9 returns per spawner—a substantial overestimate. In this example, estimates of annual productivities for escapements adjacent to the low escapement years would be systematically underestimated as a result of the misallocation of returns.

We evaluated the potential bias as a function of spawner level for escapements falling below 100 across spawning estimates from Interior Columbia population abundance data sets. We calculated median values across estimates grouped in increments of 10 and 25. We estimated the potential bias associated with the median ratios for each group under two different productivity assumptions: a) productivity in the adjacent brood years was equal; and b) productivity in the low escapement year was one 50% of the average productivity for the adjacent years in the series. The results of this simplified exercise indicate that the bias induced in estimates of productivity at low abundance can substantially inflate productivity estimates (Table A-1). The estimated impacts dropped rapidly as the number of spawners increased from 10 towards 50.

Misallocation of spawners to a particular brood year also affects productivity estimates at higher escapement levels. Median ratios of relative escapements in adjacent brood years approach one at higher escapement levels, indicating that the impact of misallocation by age would not result in a directional bias, but would largely translate into increased variance in estimated productivities.

Table A-1. Impact of bias in allocating returns on estimates of brood year specific productivities. Impact illustrated for two relative productivity scenarios: 1) actual productivity for low spawner escapement year equal to productivity for adjacent spawning years; and 2) actual productivity of low spawner brood year 50% of value for adjacent spawning years.

Number of Parent Spawners in $Year_n$	Median Ratio: $Spawners(yr_n)$ to Spawners (yr_{n+1}, yr_{n-1}).)	Relative Bias: Estimated Productivity ($Year_n$)	
		$Year_n$ Productivity EQUAL TO $Year_{n-1,+1}$ Productivity	$Year_n$ Productivity 50% OF $Year_{n-1,+1}$ Productivity
2 to 10	15.8 : 1	8.40 X	16.3 X
11 to 20	3.1 : 1	2.05 X	3.6 X
21 to 30	2.7 : 1	1.85 X	3.2 X
31 to 40	2.3 : 1	1.65 X	2.80 X
41 to 50	1.5 : 1	1.25 X	1.75 X
50 to 75	1.7 : 1	1.35 X	2.20 X
76 to 100	1.5 : 1	1.25 X	2.00 X

Demographic Risk at Very Low Spawner Abundance

Given the production observed at low escapements, we also developed a simple stochastic simulation of demographics at very low population sizes to inform a revision of the RFT estimate. Spawning ground survey results indicate that spawning redds are often dispersed across several spawning sites within a population even at very low spawning densities. Under those circumstances the probability that one or more females may return to a site without male spawners. We set up a hypothetical population model assuming three spawning areas. We assumed that the average ratio of males to females was 1:1, with annual returns following a binomial distribution and that returning males and females would randomly distribute among the three spawning areas. We generated 1,000 iterations of the model for total spawning returns ranging from 2 to 16. We calculated the effective number of female spawners for each model iteration, defining an effective female spawner as a female return to a spawning area occupied by at least one male spawner. We averaged the proportion of effective female spawners across 1,000 iterations at each spawning level tested (Figure A-7). The expected proportion of effective female spawners decreased from greater than 0.90 to less than 0.80 as spawner numbers declined to below 10. Below this range, the proportion of effective spawners in this simple model decreased substantially as a function of decreasing return levels.

The results of these simple simulations supported setting an RFT of 10 spawners in the model for generating viability curves for yearling chinook populations. Upper Columbia steelhead populations also utilize tributary habitats for spawning and extended rearing. We applied the same RFT in developing viability curves for these populations. The primary spawning and rearing habitat for Snake River fall chinook is in the mainstem of the Snake River and the lower reaches of major tributaries. Spawning areas within the remaining population of Snake River fall chinook are distributed in relatively small patches across over 100 km of the mainstem Snake River. As a result, we retained a higher RFT of 50 spawners in generating a set of viability curves for application to the Snake River fall chinook population.

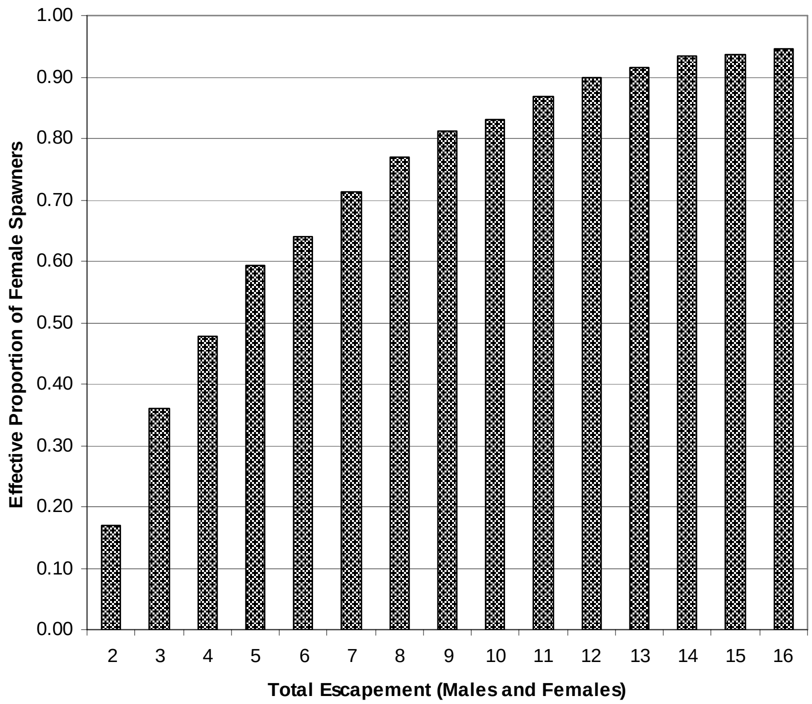


Figure A-7: Hypothetical three spawning area model. Proportion of returning females returning to a sub area with at least one male spawner present. Assumptions: 1:1 male to female ratio (binomial distribution), equal probabilities of migrating to any of the three areas. Effective proportion female spawners = effective female spawners/total female returns.

Model Mechanics

We used a cohort-based extinction risk model (described below) to calculate a standard set of viability curves for application to each ESU. The initial step in deriving a viability curve was the selection of a target risk level/time period, we generated curves corresponding to 1%, 5% and 25% risks of quasi-extinction over a 100 year timeframe.

Automated Grid Search Routine

Viability curves were generated by iteratively running the cohort model through a range of productivity and abundance combinations using an automated grid search routine. We used ESU-specific geomean return rate variance and autocorrelation estimates along with averaged age at return proportions as inputs into the model runs. We used the extinction risk model in conjunction with a binary search algorithm to estimate the equilibrium abundance associated with each individual productivity value in the series that yielded the target risk. The model can either be run in batch mode to search for the specific abundance levels associated with each productivity in an input series of values or to find the abundance corresponding to a particular productivity value.

For a given productivity, the model was run with the user-specified upper and lower abundance bounds, and extinction risk was evaluated for both runs. If the target extinction fell between the risks associated with both bounds, the algorithm would seed the model with the abundance halfway between the two previous values. The algorithm continued seeding the model using this “halfway” method until the resulting risk was within 7% of the target risk. At this point, 4000 iterations per run were used to minimize the risk of missing the appropriate abundance. Using 4000 iterations instead of the customary 1000 enabled a more stable and fine-scale risk analysis. Once an extinction risk within 0.5% of the target risk was found, the corresponding abundance value was recorded and the model moved on to the next productivity value in the series. After completing the entire series, the results were used to plot a rough viability curve. The derived values were used to seed the model for a final series of fine-scale iterations to improve accuracy and to smooth the curve.

Cohort Model Structure

User defined values were used to set average productivity and capacity terms specific to the stock recruit function used in the analysis. We used a form of the ‘Hockey Stick’ function in generating the ESU-specific population viability curves presented in this report. A simple modification to the model allows for running the analyses with a Beverton- Holt or a Ricker function (note that the productivity and capacity input values would need to be expressed in the corresponding metrics). The productivity and abundance parameters in the extinction risk model were expressed in terms that can be directly related to estimates that can be derived from abundance data series available for many Interior Columbia populations (equation A-1).

$$R(t) = A * MIN\ (S(t), SB) * \mathcal{E}(t) \qquad \text{eq. A-1}$$

Where:

> *R(t) = Expected number of adult returns to the spawning area in future years resulting from brood year escapement S(t).*
>
> *S(t) = Parent year adult escapement.*
>
> *SB = Spawner Breakpoint: number of spawners corresponding to breakpoint of hockey stick function.*
>
> *A = Productivity: Estimated as geomean return/spawner at spawning abundance below SB.*
>
> $\varepsilon(i)$ = *process error: random variable, lognormal distribution with a mean of 0, standard deviation of σ.*

Running the Model

Each modeled population projection is seeded with a series of five consecutive escapement values (years -4 to 0). For viability curve generation, the model was seeded with the spawner number being evaluated for the particular iteration of the grid search routine. The cohort model can also be used to generate an estimate of risk using population specific current abundance and productivity estimates. For a risk assessment of an individual stock, we used the five most recent spawning escapements as initial values.

Step 1—generating a population projection

The model steps through the escapement series, sequentially generating an estimate of production for each parent escapement. If the parent escapement value is below the user-defined reproductive failure threshold (RFT), the production from that brood year is set to zero. If the adult escapement exceeds the RFT, the model generates an initial production estimate using the embedded stock-recruit function with productivity and capacity terms based on the input values for the particular model run. The model applies an annual deviation to projected returns from each parent year based on a random draw from a normal distribution defined by estimates of ESU specific averages of variance and autocorrelation. The resulting production from spawning in year (t) is allocated to future returns by applying the user-defined average age distribution. Although age structure was kept static while generating the viability curves, the model was designed so that the user can add stochasticity to the annual brood year age distribution if desired.

The model incorporates autocorrelation into the annual stochastic error term adapting the approach described in Morris & Doak (2002). We used average variance and autocorrelation estimates corresponding to each ESU (see the Population Statistics section below). The model works in annual time steps. A run is initiated by calculating the expected production from the spawning escapement in year 1 and multiplying the result by a factor drawn from a lognormal distribution with mean of 0 and a standard deviation of σ, where σ is the average ESU value. The stochastic error term for year 2 and all subsequent production years is modified to incorporate autocorrelation:

$$\varepsilon(t) = \rho * \varepsilon(t-1) + \sigma' \qquad \text{eq. A-2}$$

where ρ is the simple correlation coefficient between sequential annual deviations from expected productivity calculated from the data series for the corresponding ESU and the term $\mathcal{E}$ (0,σ') represents the portion of the variance in the data series not accounted for by autocorrelation. The adjusted standard deviation in that term, σ', is calculated as:

$$\sigma' \cong \sqrt{\sigma^2} * \sqrt{1-\rho^2} \qquad \text{eq. A-3}$$

Model year 1 is the first year in each projection that is totally generated by the model (not an initial seed escapement). The model generates an estimate of adult escapement in year 1 by adding together the projected number of 5 year olds produced from the initial seed escapement in year (-4) and the projected number of 4 year old adults produced from initial seed escapement year (-3). The model repeats steps 1 and 2, generating a time series of at least 100 years.

Step 2—projection iteration

At the end of a 100+ year population projection, the model stores the series of annual abundance estimates in a temporary results file or virtual array. Under the basic set-up, 1000 projections (replicates) of 100+ years for each set of input parameters are generated during a model run. Each projection is based on the same input parameters (capacity and starting escapement values, variance, autocorrelation, and age structure), but reflects a unique combination of random draws from the distribution defined by the variance and autocorrelation input values. In other words, each projection for a particular set of model inputs represents an alternative potential future pattern in returns over a 100+ year time period that is consistent with that particular set of model inputs.

Step 3—Compiling a Risk Estimate

After 1,000 projections are accumulated, the model summarizes the results according to the specific risk target metrics input into the model. If the parent escapement from any four consecutive years leading up to (and including) the user-specified timeframe are all less than the QET, then the projection is counted as an extinction. We evaluated the projected risk of extinction over a 100-year period. Finally, the extinction risk for the entire run is calculated as the proportion of projections that were counted as extinct.

Minimum Abundance Thresholds

Populations of listed chinook and steelhead within Interior Columbia ESUs vary considerably in terms of the total area available to support spawning and rearing.

We add a minimum abundance threshold to our ESU specific viability curves corresponding estimates of the historical amount and complexity of tributary spawning habitat for a population. The minimum abundance thresholds were incorporated into the ESU specific viability curves to ensure that the full range of objectives defined for productivity and abundance are achieved, including the desire to maintain genetic characteristics and to maintain sufficient spawner densities in larger tributary habitats. A more detailed discussion of the rationale for the specific minimum abundance thresholds is included in the population viability criteria section of the ICTRT document and in Attachment B.

ESU-Specific Viability Curves

We generated sets of viability curves for application to populations within each of the Interior Columbia ESUs. We used ESU average estimates of variance and autocorrelation derived from representative trend data sets combined with minimum abundance thresholds specific to the general population size categories to generate curves. In addition to depicting the 5% risk of extinction threshold for evaluating population viability, the figures also include risk thresholds corresponding to a relatively high risk of extinction (10% and 25% in 100 years) and a lower risk level (1% in 100 years). We adapted the approach to accommodate the relatively limited amount of data available for Snake River Fall Chinook and Sockeye populations.

We analyzed the incremental and combined effects of filtering the data sets for factors that could inflate population level estimates of variability in return rates: multiple years with very low parent spawning levels, chronic high hatchery origin spawners, and incorporating a specific form of the spawner recruit relationship with relatively poor statistical fit across the data sets. The specific criteria used to screen populations for these factors are summarized in Table A-2.

Table A-2. Screening criteria used to develop representative estimates of variance and autocorrelation in productivity for input into ESU specific viability curve projections.

Factor	Criteria
1. Multiple spawnings at extreme low numbers	Most recent 20 year geomean of adult spawners less than 50 per year
2. Multiple years with high hatchery origin spawner proportions	Most recent 20 year average proportion hatchery (to spawning grounds) of greater than 30%.
3. High proportion and annual variability in hatchery proportion	High proportion screen plus standard deviation of hatchery proportion exceeds 30%
4. Worst fit statistical model (across populations)	Based on comparative AICc analyses within ESU populations. Drop model that most often scores lowest (by at least 2 AICc points) across populations within the ESU
5. Combination (1&2) multiple low and high potential hatchery influence	Apply criteria for factors 1 & 2
6. Combination (1&2) plus eliminate worst fit model (4)	Apply criteria for factors 1, 2 and 4

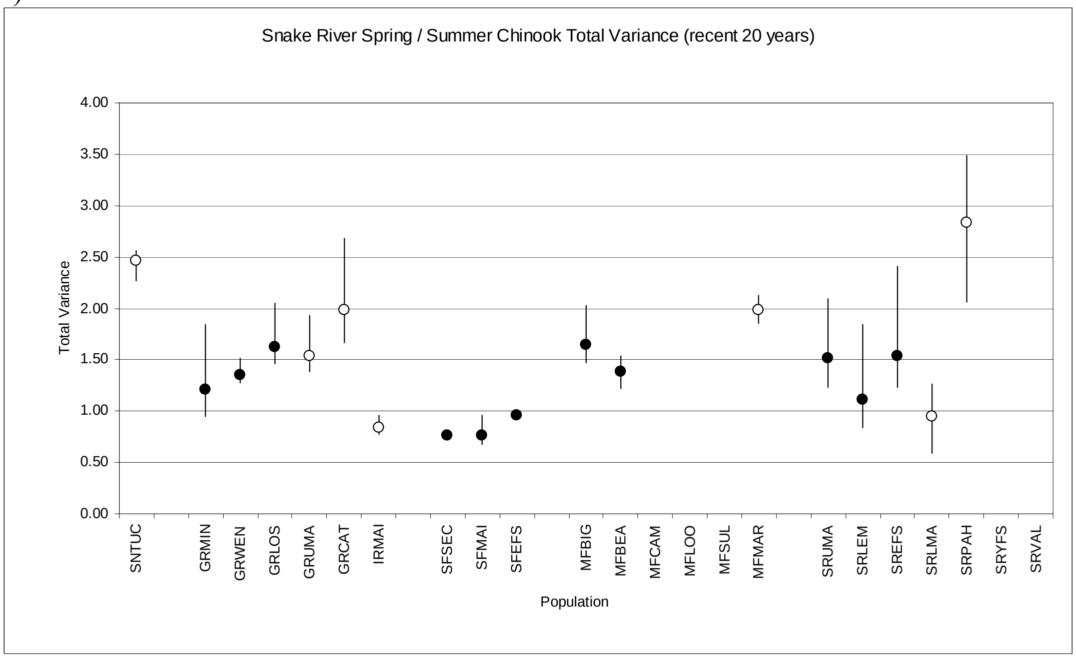
Snake River Spring/Summer Chinook ESU

We have developed 23 population specific data series for this ESU. Population level estimates of the variance and autocorrelation are depicted in Figure A-8. The average total variance and autocorrelation estimates based on all 23 population data series increased relative to the averages for the 12 data series available for the first draft of this analysis (ICTRT 2005a). Updates to the individual data series included in the original set accounted for a small component of the increase in both parameters (Table A-3). Most of the increase was due to the addition of the 11 new data series. The geomean in parent spawning levels were below 50 for five of the data series for this ESU, indicating multiple years with very low spawning numbers. The variance in return rates at very low spawning levels is likely significantly increased. Dropping those five data series from calculating the average resulted in reduced total variance and a moderate increase in average autocorrelation. Six of the twenty-three populations had relatively high inputs of hatchery origin fish into natural spawning across the 20 year time frame. Dropping those six populations from the analysis resulted in increased average total variance and autocorrelation. Excluding the s/r function with the worst fit across populations (Random Walk) resulted in reduced total variance and elevated average autocorrelations. Applying all three of the criteria drops ten population data sets from the analysis. The resulting average total variance is 1.24, approximately 10% higher than the estimate based on the original set of 12 population data series.

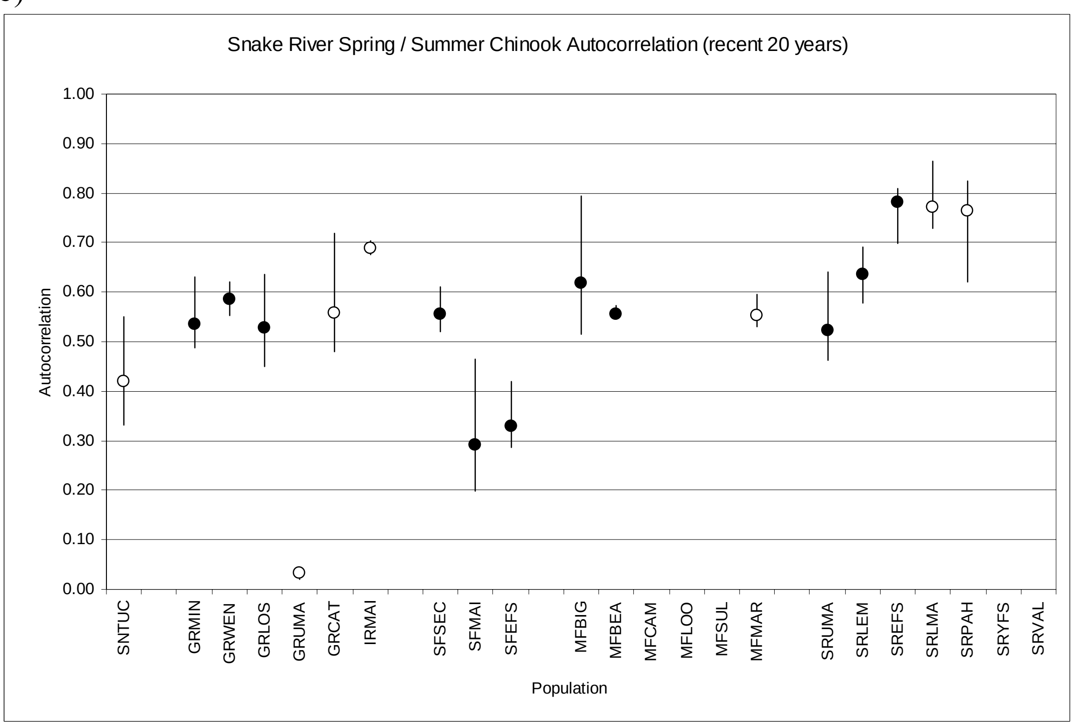
The viability curves generated for application to populations of Snake River spring/summer chinook within each of the four historical population size categories are depicted in Figure A-12a-d.

Figure A-8a-c. Population estimates of productivity (geomean brood year spawner to spawner return rates) statistics for the Snake River spring summer chinook ESU: a) total variance; b) autocorrelation; c) adjusted variance (after accounting for autocorrelation). Bars represent +/- 1 standard error. Filled symbols indicate population data series that met filters described in text.

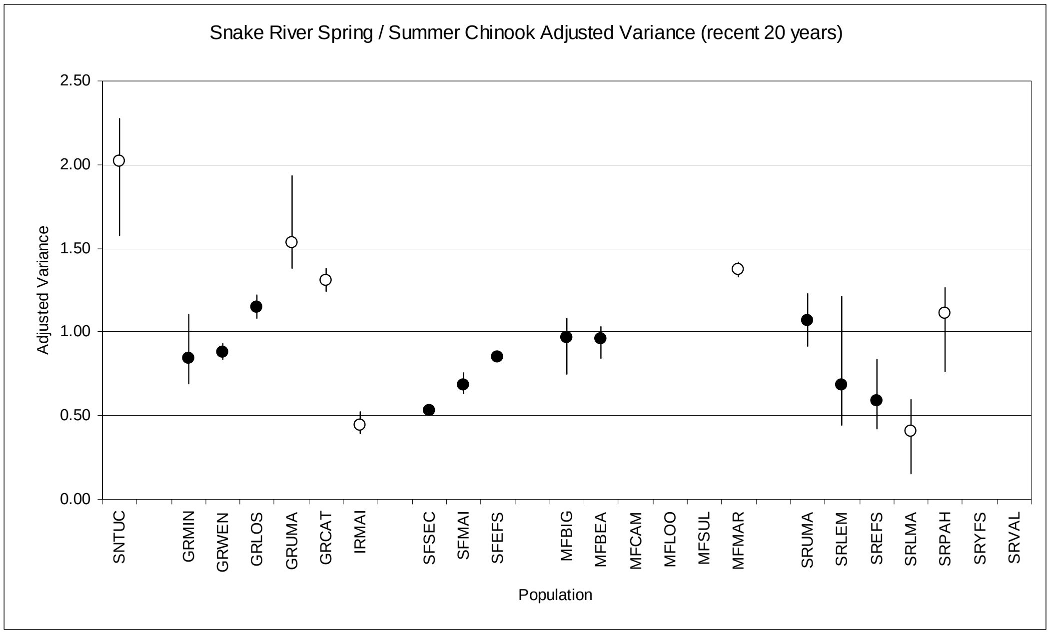
a)



b)



c)


Snake River Spring / Summer Chinook Adjusted Variance (recent 20 years)
Adjusted Variance
2.50
2.00
1.50
1.00
0.50
0.00
SNTUC
GRMIN
GRWEN
GRLOS
GRUMA
GRCAT
IRMAI
SFSEC
SFMAI
SFEFS
MFBIG
MFBEA
MFCAM
MFLOO
MFSUL
MFMAR
SRUMA
SRLEM
SREFS
SRLMA
SRPAH
SRYFS
SRVAL
Population

Upper Columbia Spring Chinook ESU

The original analysis included data sets for all three of the extant populations in the Upper Columbia spring chinook ESU. Updates to the data sets resulted in a small increase (roughly 3%) in total variance (Table A-3). Estimated average autocorrelation remained at the same value (0.68). None of the data sets were eliminated by the geomean population size and hatchery contribution tests. Eliminating the worst fit s/r model across the data series reduced the total variance to 0.95, approximately 3% below the original values.

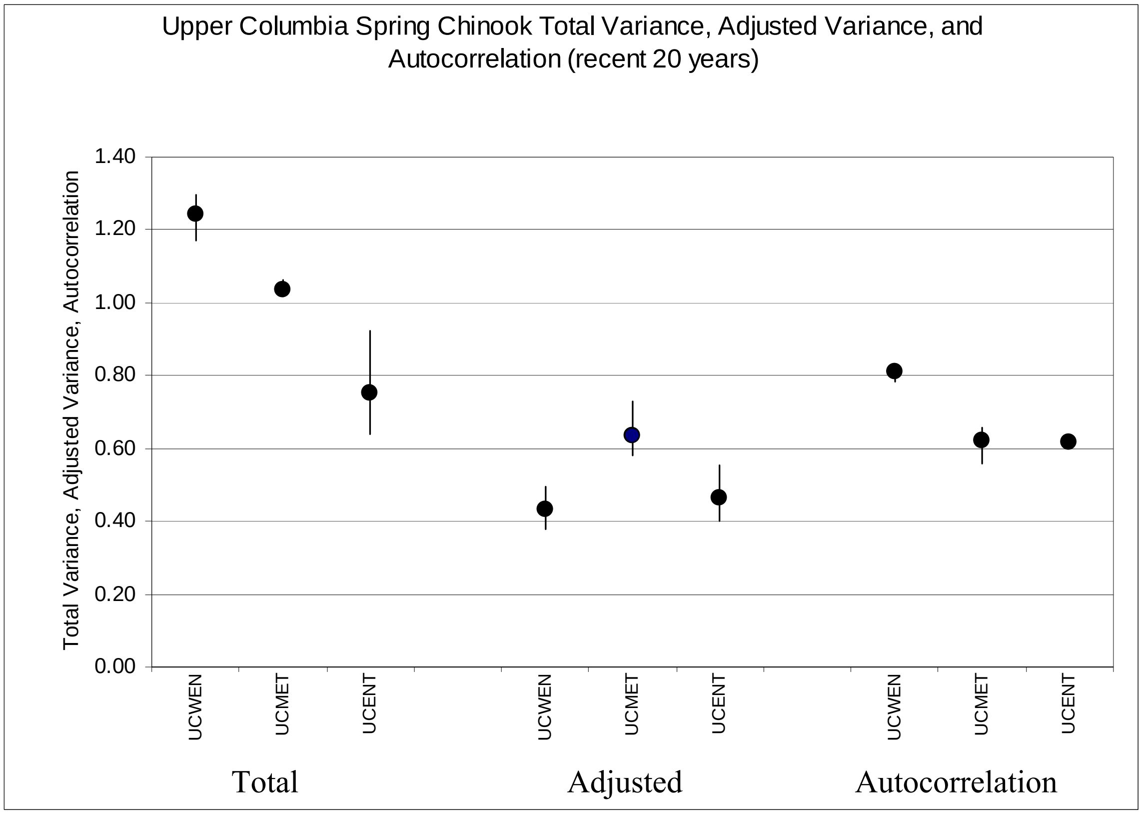


Figure A-9. Population estimates of productivity (geomean brood year spawner to spawner return rates) statistics for the Upper Columbia Spring Chinook ESU. Total variance, autocorrelation, and adjusted variance (after accounting for autocorrelation) are shown. Bars represent +/- 1 standard error. Filled symbols indicate population data series that met filters described in text.

Upper Columbia Steelhead ESU

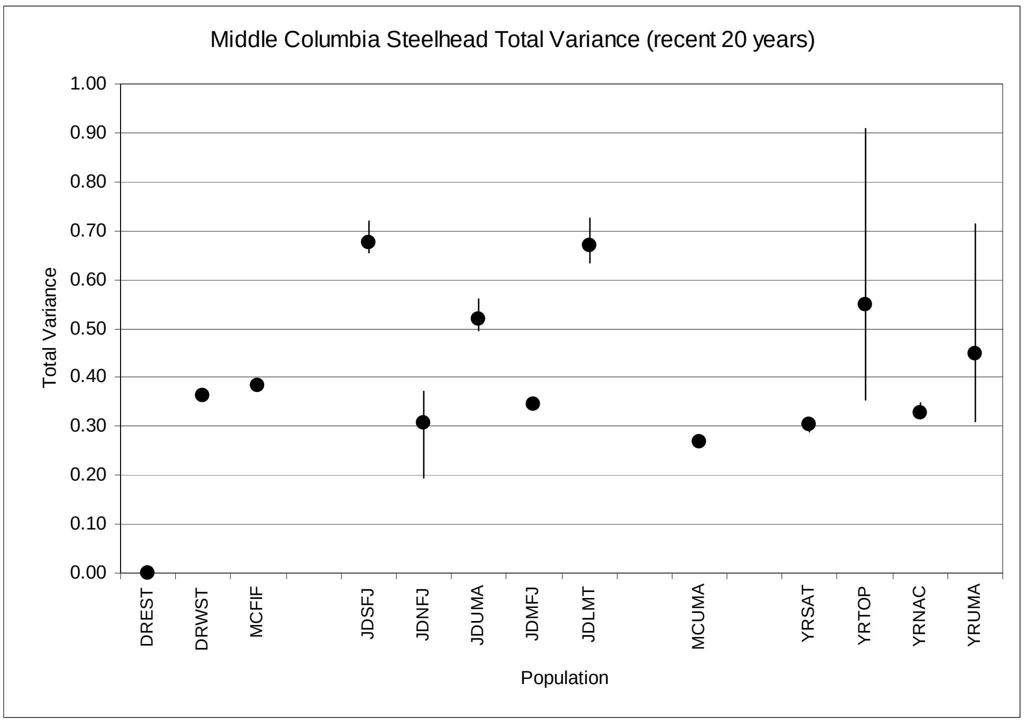
Since the ICTRT has little confidence in estimates of variance and autocorrelation for Upper Columbia Steelhead populations, combined estimates from the Mid-Columbia and Snake River steelhead ESUs were used in generating viability curves for the Upper Columbia ESU (Figures A-10 and A-11).

Mid-Columbia Steelhead ESU

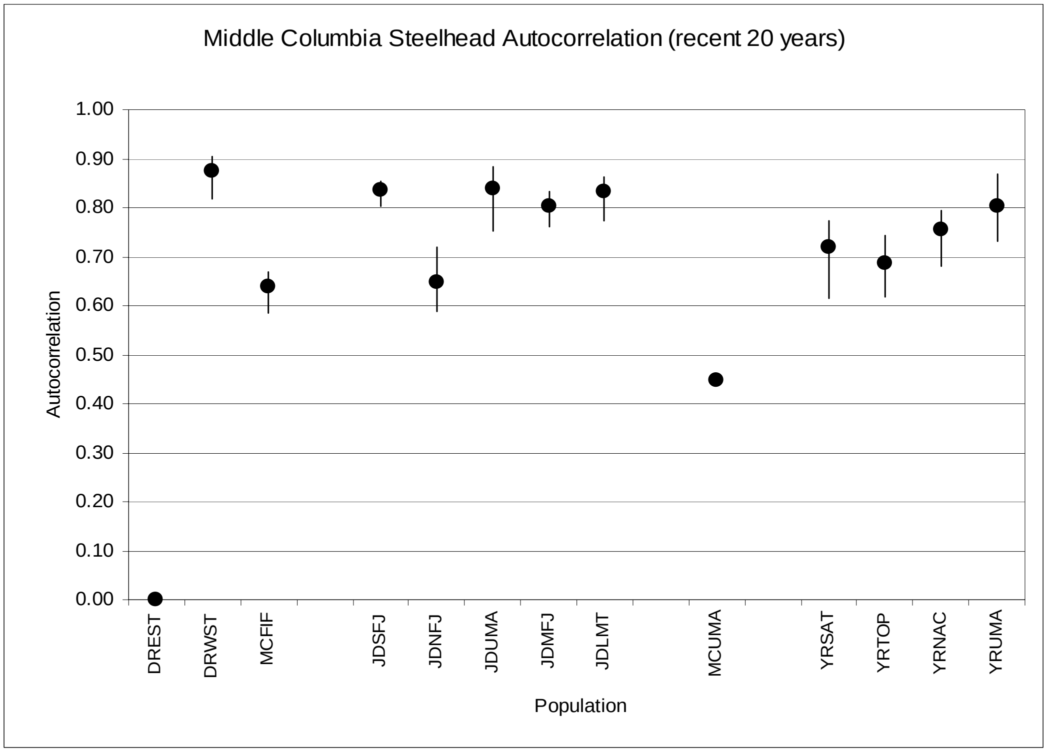
We generated variance and autocorrelation estimates using data sets representative of 13 Mid-Columbia steelhead populations (Figures A-10a-c). We calculated a set of average values across 12 of the data sets for use in generating a representative viability curve for application to populations within the ESU. We dropped the Deschutes River (Eastside) data set due to chronically high estimated proportions of hatchery origin fish on the spawning grounds.

Figure A-10a-c. Population estimates of productivity (geomean brood year spawner to spawner return rates) statistics for the Mid-Columbia Steelhead ESU. a) total variance; b) autocorrelation; c) adjusted variance (after accounting for autocorrelation). Bars represent +/- 1 standard error. Filled symbols indicate population data series that met filters described in text.

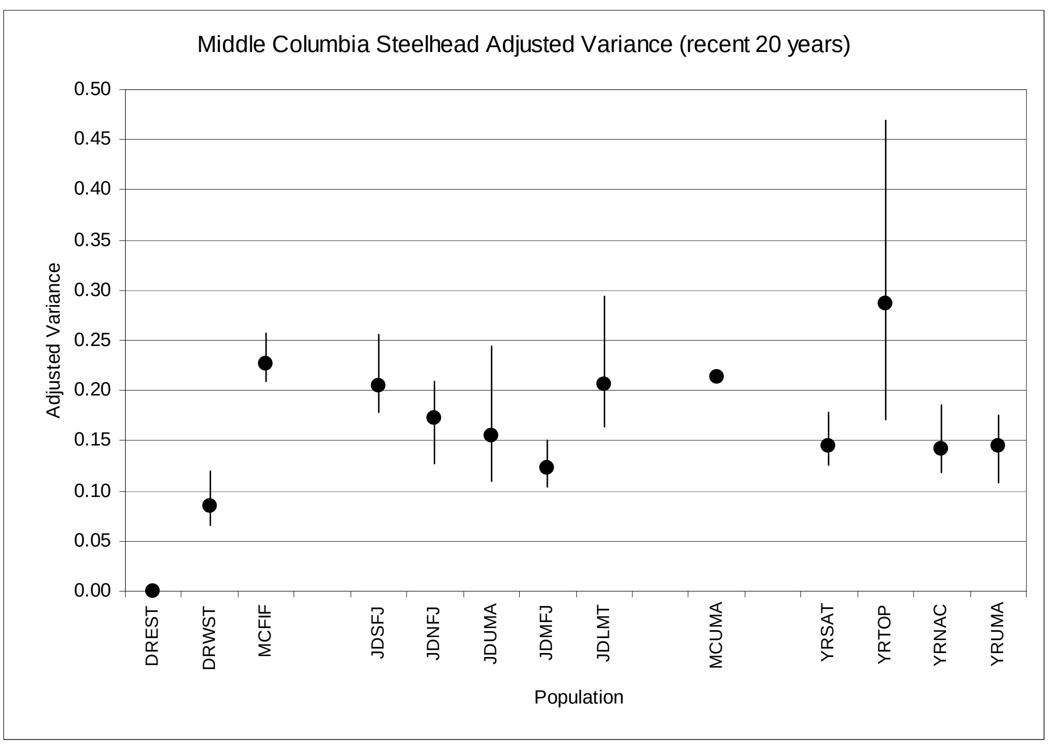
a)



b)


Middle Columbia Steelhead Autocorrelation (recent 20 years)
Autocorrelation
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
DREST
DRWST
MCFIF
JDSFJ
JDNFJ
JDUMA
JDMFJ
JDLMT
MCUMA
YRSAT
YRTOP
YRNAC
YRUMA
Population

c)


Middle Columbia Steelhead Adjusted Variance (recent 20 years)
Adjusted Variance
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
DREST
DRWST
MCFIF
JDSFJ
JDNFJ
JDUMA
JDMFJ
JDLMT
MCUMA
YRSAT
YRTOP
YRNAC
YRUMA
Population

Snake River Steelhead ESU

Population specific trend data sets area available for a relatively small proportion of populations in the Snake River Steelhead ESU. Three new population specific series have been developed in addition to the two original data sets used in previously reported ICTRT analyses. Four out of the five population specific trend series are in the Grande Ronde MPG and the adjacent Imnaha River. The only set specifically corresponding to returns to a particular location in the Idaho portion of the ESU was based on weir counts of fish returning to a section within the Little Salmon River population. Annual counts of wild and hatchery steelhead passing over Lower Granite Dam are available. These aggregate counts represent the combined returns to all populations and hatchery facilities above Lower Granite Dam and include the returns accounted for by the estimates described above. The Lower Granite counts can be broken down into A and B type steelhead runs (TAC ref). The populations with available trend series are all classified as Type A stocks. To complement the population specific trend data sets, we calculated return rate statistics (variance and autocorrelations) for average A and B run populations assuming that the returns not accounted for in the available population sets were distributed among the remaining populations proportional to intrinsic potential habitat.

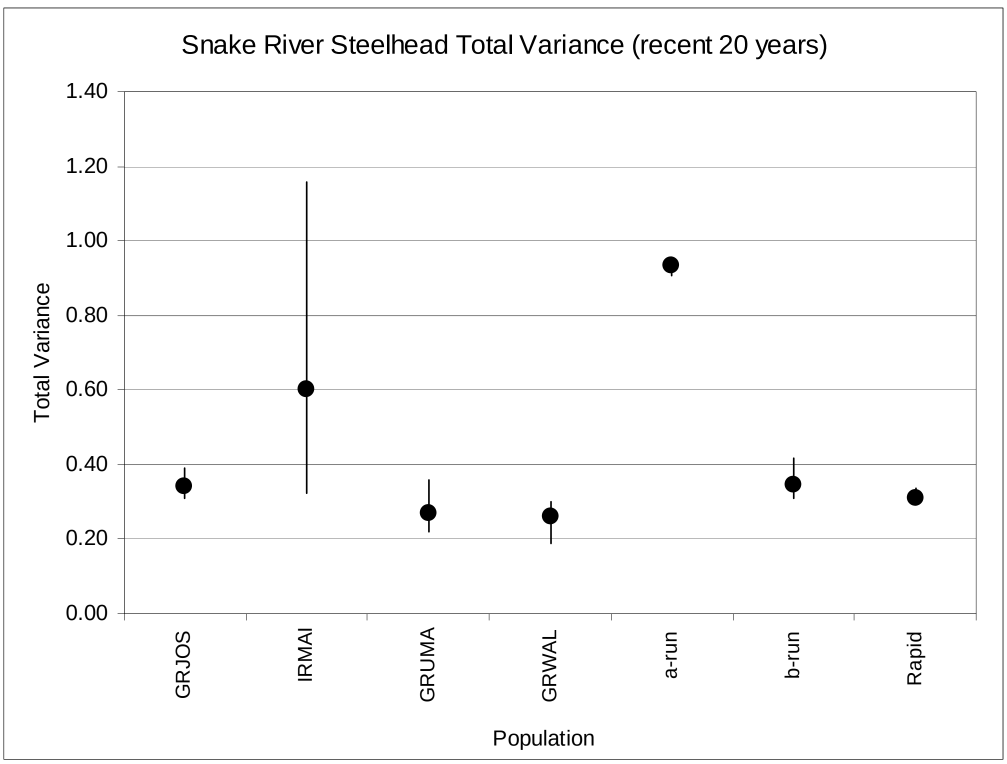
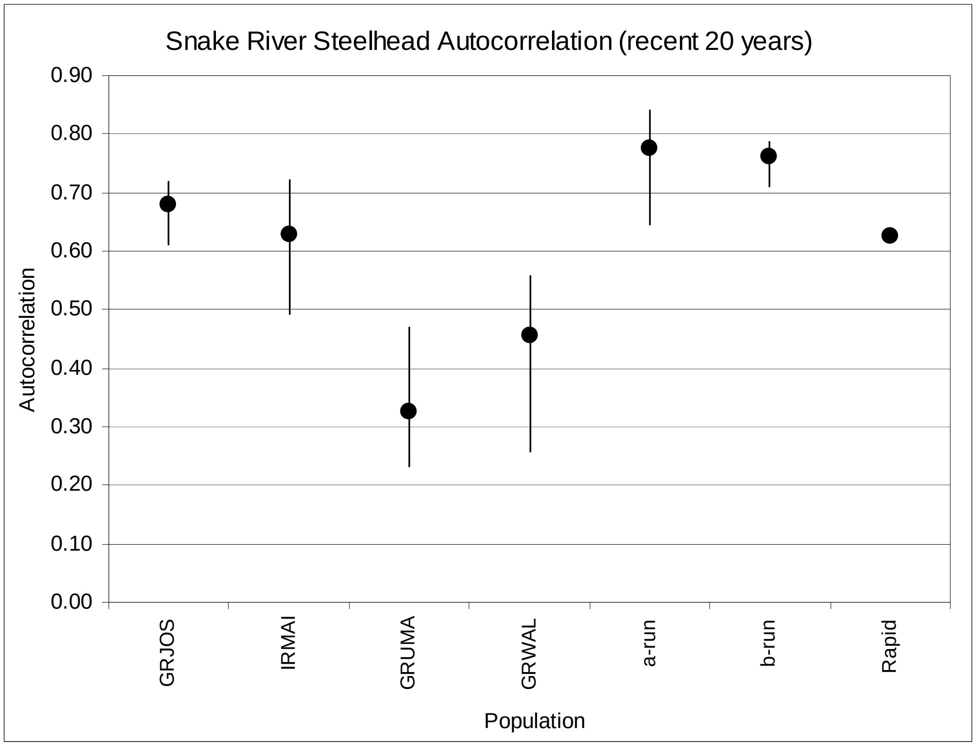


Figure A-11a-c. Population estimates of productivity (geomean brood year spawner to spawner return rates) statistics for the Snake River Steelhead ESU. a) total variance; b) autocorrelation; c) adjusted variance (after accounting for autocorrelation). Bars represent +/- 1 standard error. Filled symbols indicate population data series that met filters described in text.

b)


Snake River Steelhead Autocorrelation (recent 20 years)
Autocorrelation
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
GRJOS
IRMAI
GRUMA
GRWAL
a-run
b-run
Rapid
Population

c)

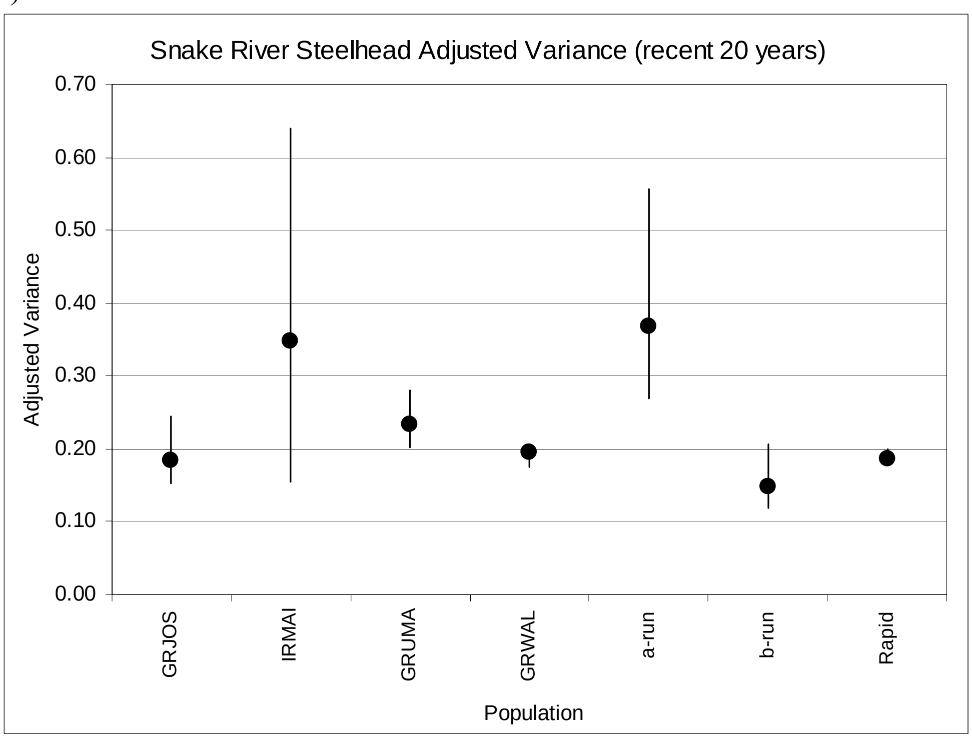

Snake River Steelhead Adjusted Variance (recent 20 years)
Adjusted Variance
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
GRJOS
IRMAI
GRUMA
GRWAL
a-run
b-run
Rapid
Population

Table A-3. Summary statistics by ESU. Average variance and autocorrelation of residuals from stock/recruit function fits.

		Snake River Spring / Summer Chinook				**Upper Columbia Spring Chinook**			
	Method	***# of Pops***	***Total Var.***	***Auto***	***Adj. Var.***	***# of Pops***	***Total Var.***	***Auto***	***Adj. Var.***
1	***Original Values***	12	1.18	0.44	0.95	3	0.99	0.68	0.53
2	***Updated Values w original populations***	12	1.29	0.49	0.94	3	1.02	0.68	0.55
3	***Updated Values w all populations***	23	1.52	0.54	1.08	3	1.02	0.68	0.55
4	***no pops w parent esc geomean<50***	18	1.37	0.54	0.97	3	1.02	0.68	0.55
5	***no pops w hatchery > 30%***	18	1.54	0.54	1.09	3	1.02	0.68	0.55
6	***no pops w hatchery OR Stdev > 30%***	17	1.55	0.54	1.10	3	1.02	0.68	0.55
7	***exclude worst fit model***	23	1.43	0.53	1.03	3	0.95	0.68	0.51
8	***4 & 5***	13	1.33	0.55	0.93	3	1.02	0.68	0.55
9	***4, 5 & 7***	13	1.24	0.53	0.89	3	0.95	0.68	0.51

		Snake River Steelhead				Middle Columbia Steelhead			
Number	Method	# of Pops	Total Var.	Auto	Adj. Var.	# of Pops	Total Var.	Auto	Adj. Var.
1	Original Values	2	0.49	0.54	0.35	4	0.44	0.69	0.23
2	Updated Values w original popualtions	2	0.63	0.67	0.34	7	0.54	0.74	0.20
3	Updated Values w all populations	6	0.54	0.61	0.34	13	0.51	0.74	0.23
4	no pops w parent esc geomean<50	6	0.54	0.61	0.34	13	0.51	0.74	0.23
5	no pops w hatchery > 30%	6	0.54	0.61	0.34	12	0.51	0.73	0.24
6	no pops w hatchery OR Stdev > 30%	6	0.54	0.61	0.34	12	0.51	0.73	0.24
7	exclude worst fit model	6	0.39	0.60	0.25	13	0.39	0.75	0.17
8	4 & 5	6	0.54	0.61	0.34	12	0.51	0.73	0.24
9	4, 5 & 7	6	0.39	0.60	0.25	12	0.40	0.74	0.18

		Upper Columbia Steelhead			
Number	Method	# of Pops	Total Var.	Auto	Adj. Var.
1	Original Values	6	0.46	0.64	0.27
2	Updated Values w original popualtions	9	0.56	0.73	0.23
3	Updated Values w all populations	19	0.53	0.70	0.27
4	no pops w parent esc geomean<50	19	0.53	0.70	0.27
5	no pops w hatchery > 30%	18	0.53	0.69	0.28
6	no pops w hatchery OR Stdev > 30%	18	0.53	0.69	0.28
7	exclude worst fit model	19	0.40	0.71	0.2
8	4 & 5	18	0.53	0.69	0.28
9	4, 5 & 7	18	0.38	0.69	0.2

Figure A-12a-d. Snake R. Spring/Summer Chinook ESU viability curves. Variance and autocorrelation parameters used were 0.89 and 0.53, respectively. Age distribution was 0.57 age 4, 0.43 age 5. Minimum abundance thresholds are set for basic, intermediate, and large populations, respectively (Figures a-d).

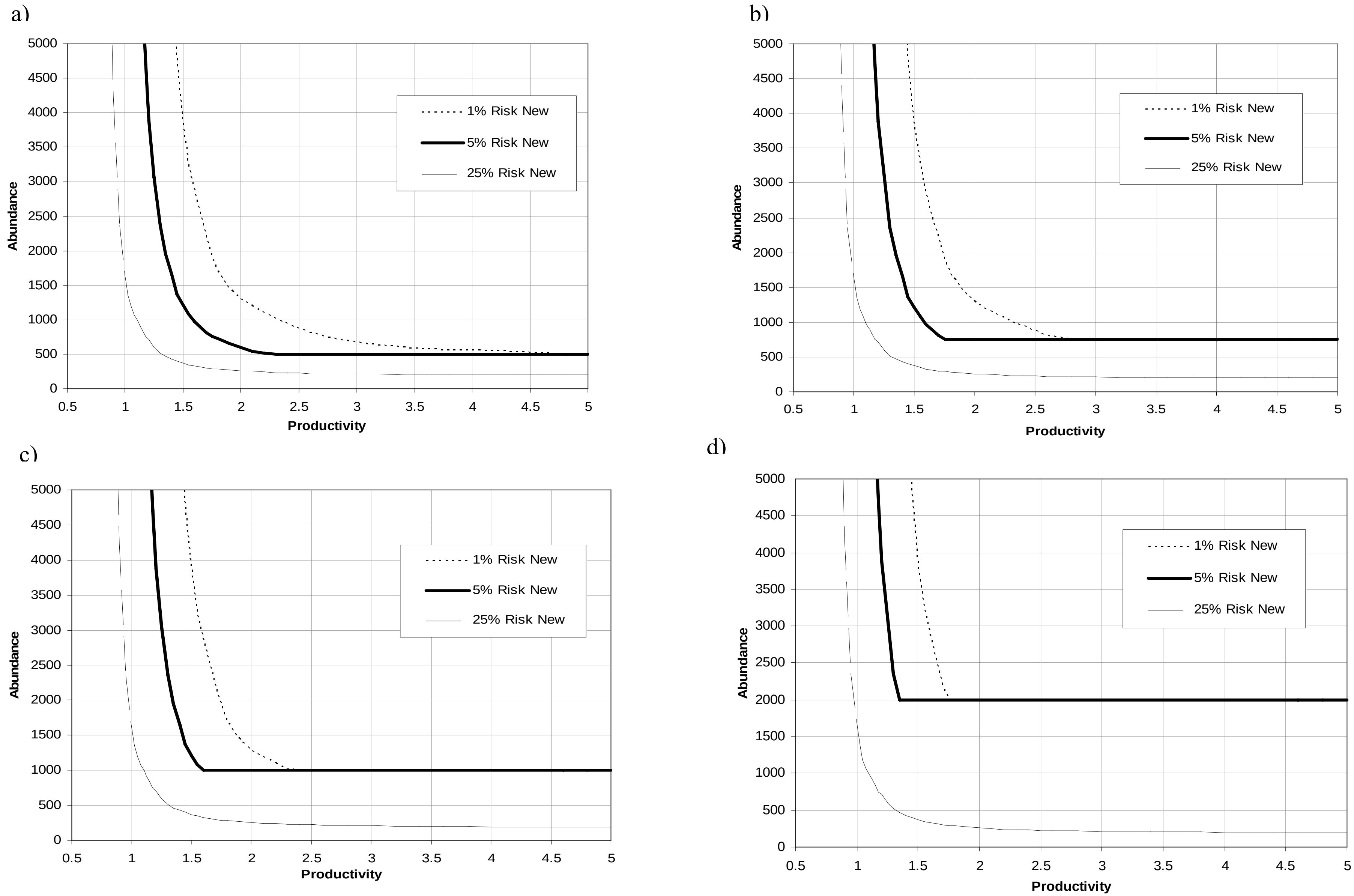
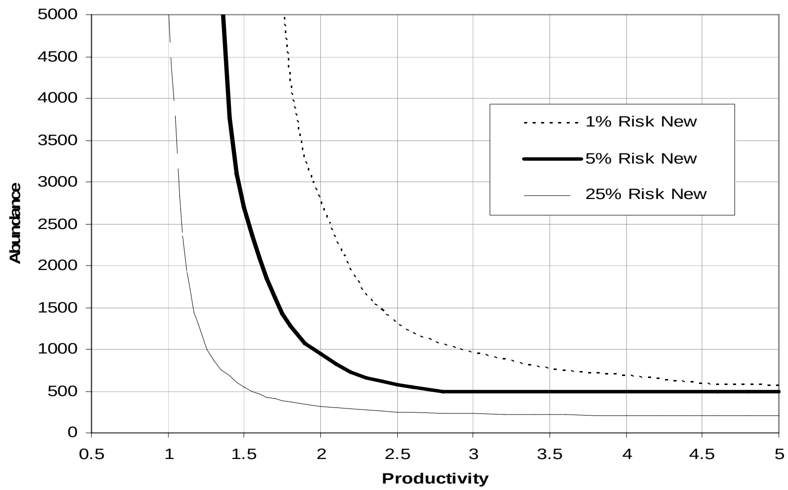
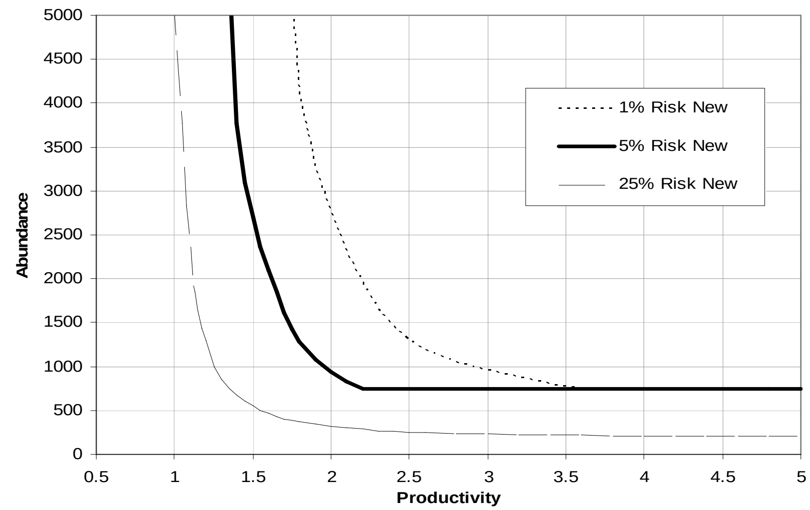


Figure A-13a-d. Upper Columbia Chinook ESU viability curves. Variance and autocorrelation parameters used were 0.51 and 0.68, respectively. Age distribution was 0.60 age 4, 0.40 age 5. Minimum abundance thresholds are set for basic, intermediate, and large populations, respectively (Figures a-d).

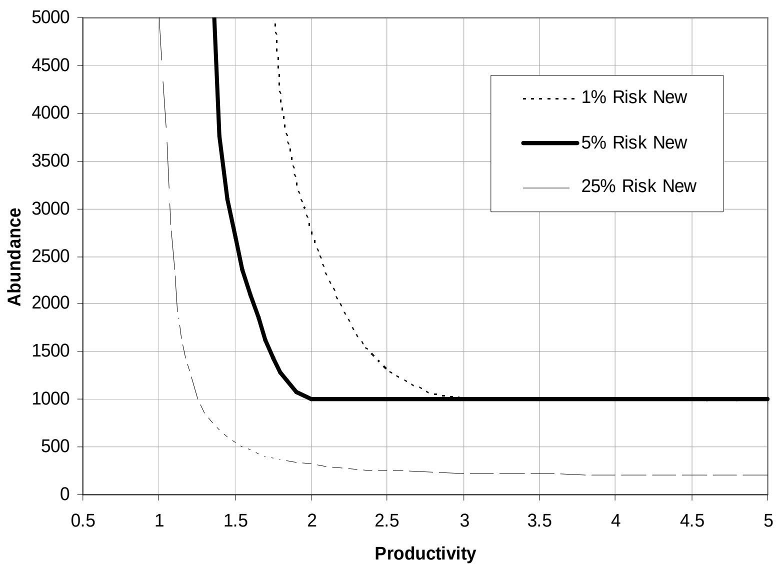
a)



b)



c)



d)

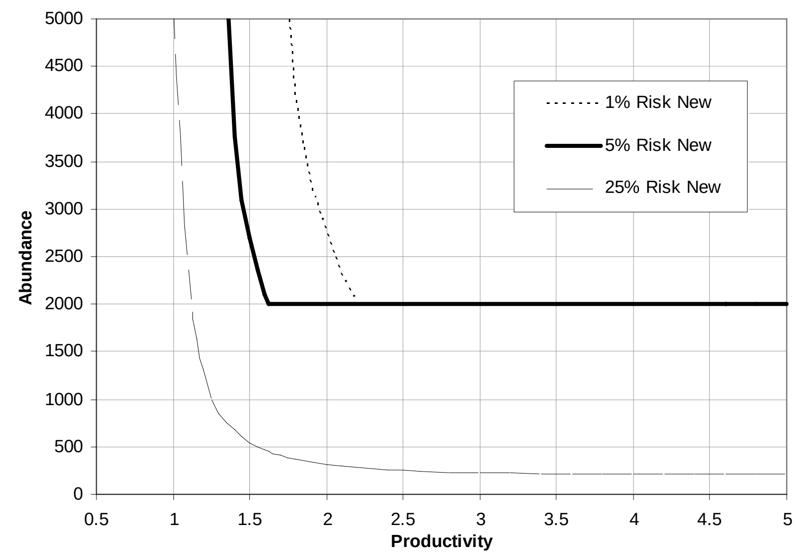


Figure A-14a-d. Upper Columbia Steelhead ESU viability curves. Variance and autocorrelation parameters used were 0.20 and 0.69, respectively. Age distribution was 0.02 age 3, 0.38 age 4, 0.45 age 5, and 0.15 age 6. Minimum abundance thresholds are set for basic, intermediate, and large populations, respectively (Figures a-d).

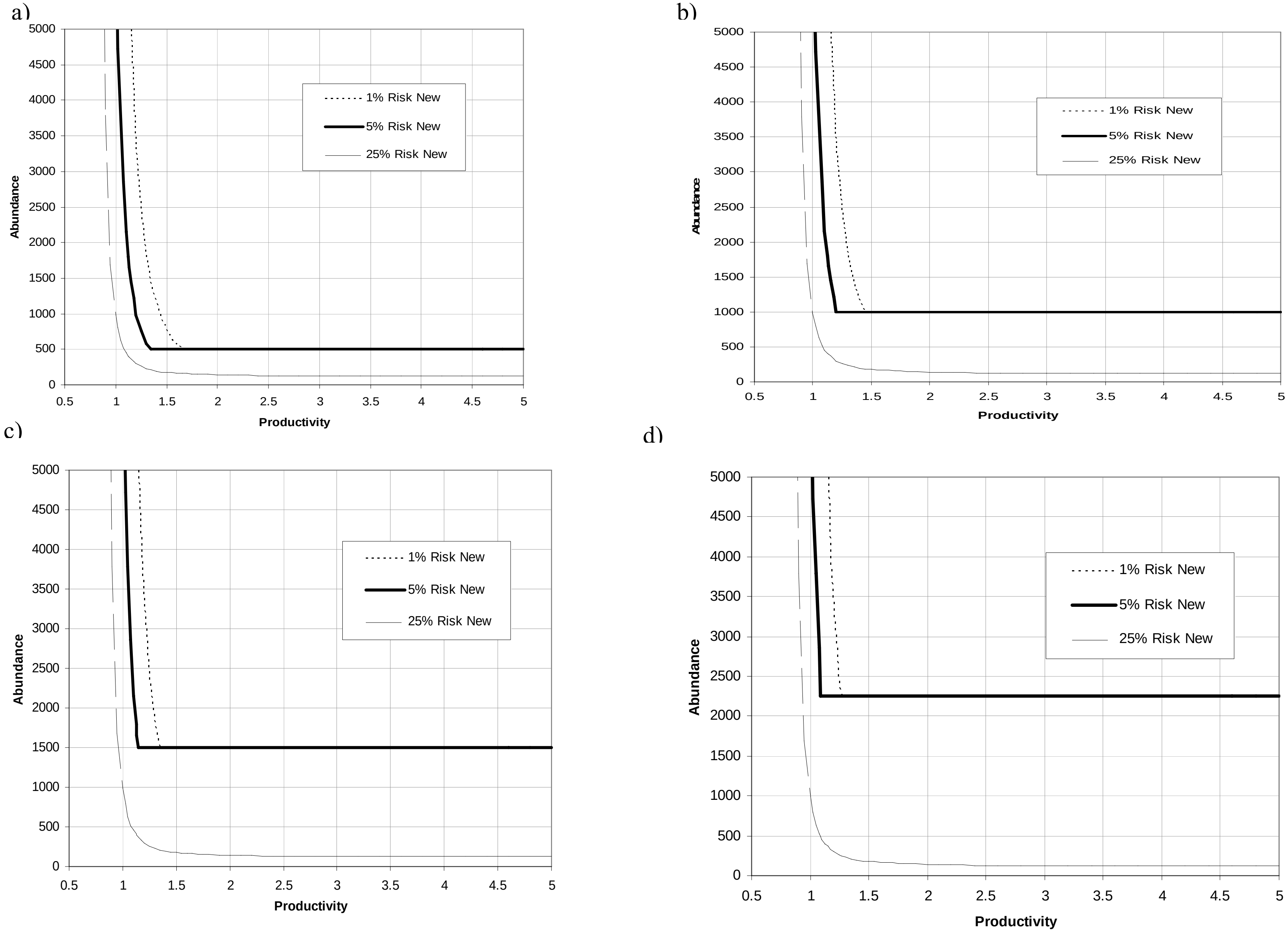
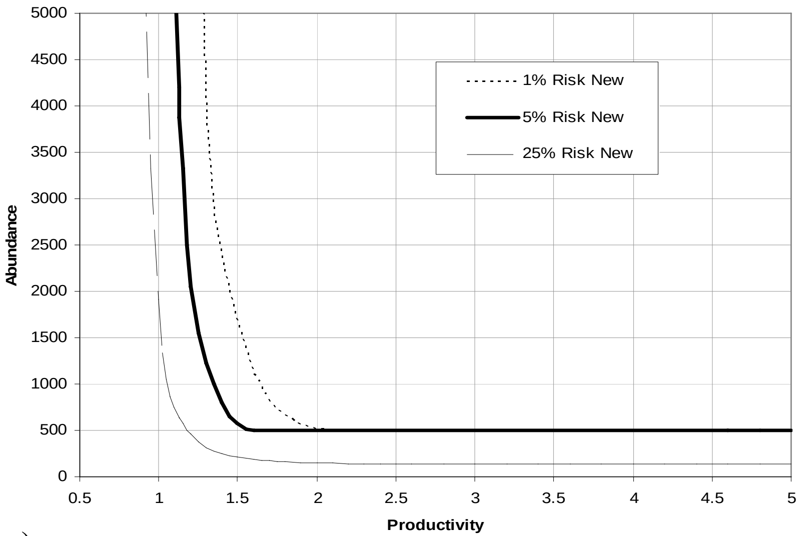
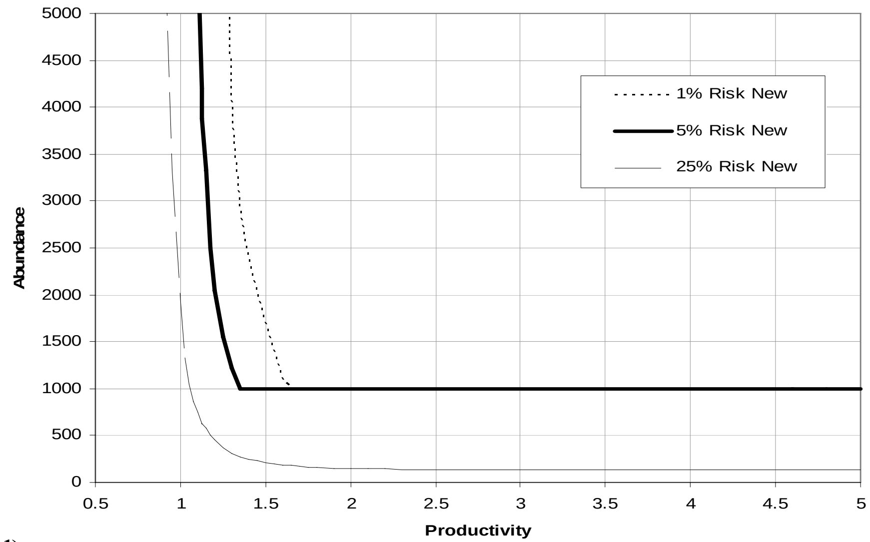


Figure A-15a-d. Middle Columbia Steelhead ESU viability curves. Variance and autocorrelation parameters used were 0.18 and 0.74, respectively. Age distribution was 0.03 age 3, 0.46 age 4, 0.43 age 5, and 0.08 age 6. Minimum abundance thresholds are set for basic, intermediate, and large populations, respectively (Figures a-d).

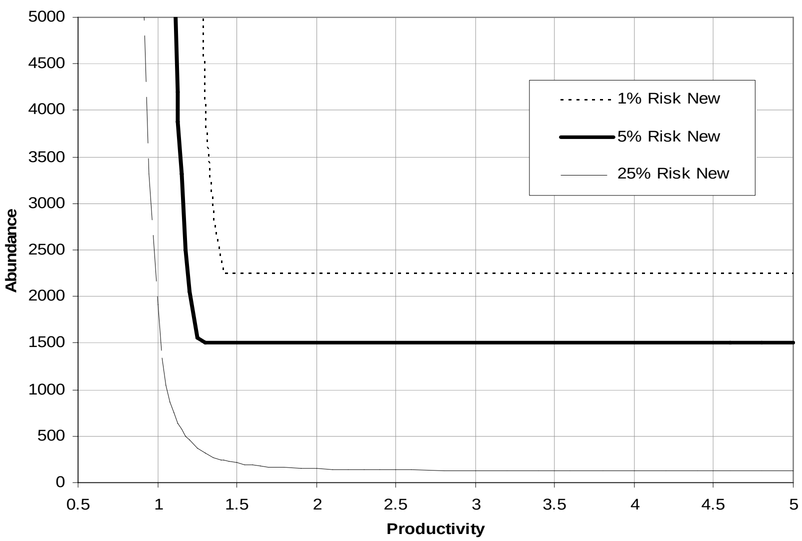
a)



b)



c)



d)

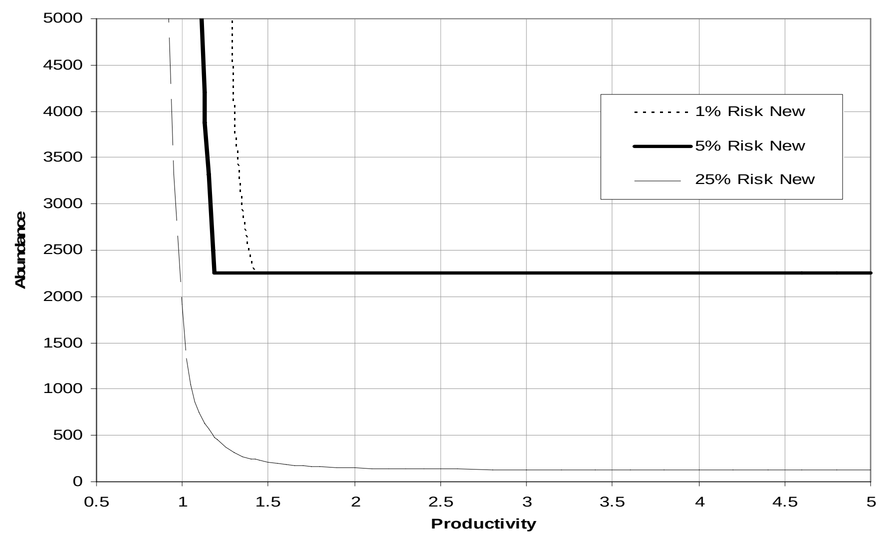
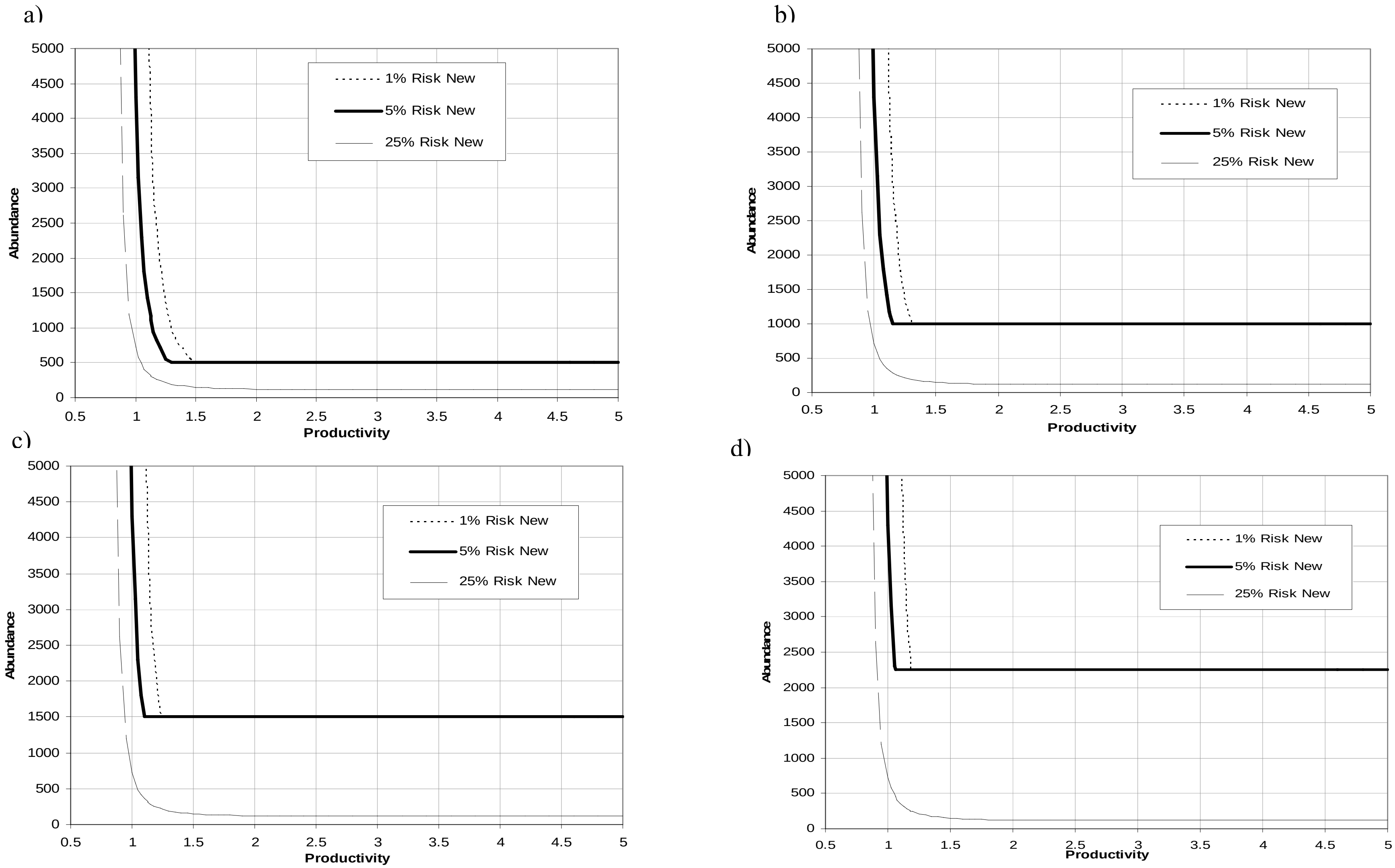


Figure A-16a-d. Snake River Steelhead ESU viability curves. Variance and autocorrelation parameters used were 0.25 and 0.60, respectively. Age distribution was 0.03 age 3, 0.60 age 4, 0.35 age 5, and 0.02 age 6. Minimum abundance thresholds are set for basic, intermediate, and large populations, respectively (Figures a-d).



Fall Chinook ESU

We calculated a viability curve for Snake River fall chinook following the same analytical steps we applied to yearling chinook and steelhead ESUs. We calculated variance and one year lag autocorrelation statistics for reconstructed brood year spawners and natural returns for 1978-2003. We used a grid-search algorithm to develop a set of viability curves for Snake River fall chinook corresponding to projected risk levels of 25%, 5% and 1% at 100 years (Figure A-17).

We established a minimum abundance threshold for fall chinook consistent with the general abundance/productivity objectives summarized in the July 2003 ICTRT Viability draft report. We are recommending a minimum abundance threshold of 3,000 natural origin spawners for the extant Snake River Fall Chinook population. No fewer than 2,500 of those natural origin spawners should be distributed in mainstem Snake River habitat.

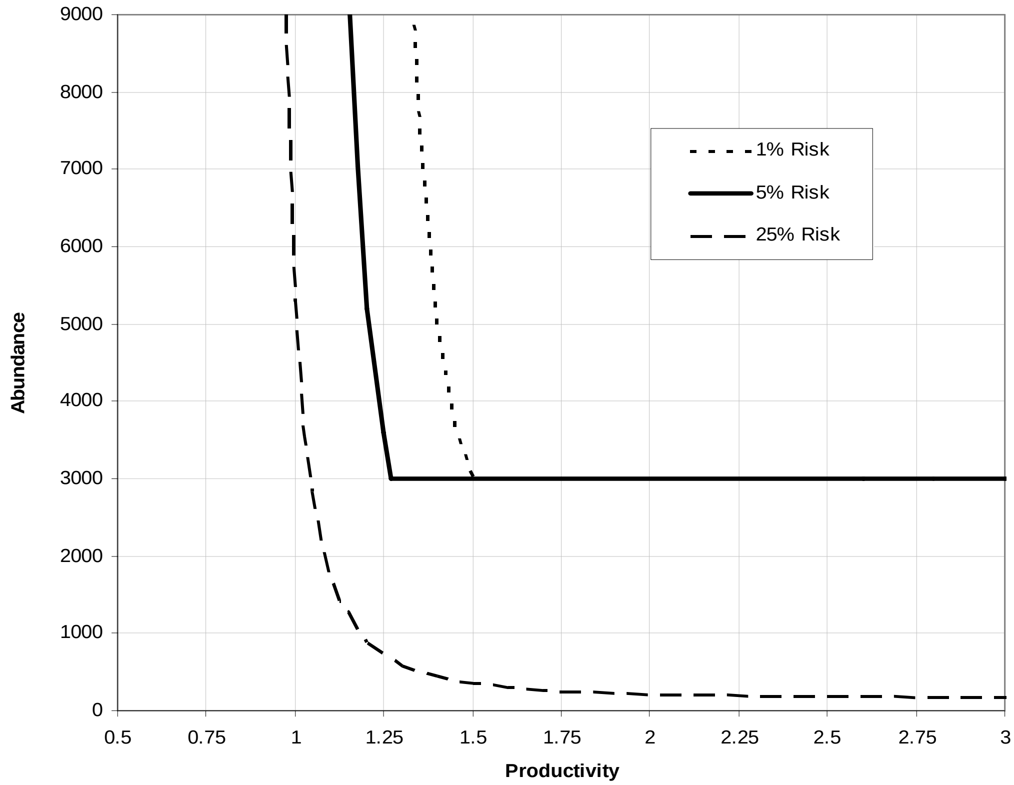


Figure A-17. Viability curves for Snake River Fall chinook. Age structure used was 53% age 3, 43% age 4, and 4% age 5. Adjusted variance (variance unexplained by autocorrelation) and autocorrelation parameters were 0.25 and 0.67, respectively.

The abundance threshold for Snake River fall chinook is based on the Bevan Team recommendation for "…an eight year (approximately 2 generation) geometic mean of at least 2,500 natural origin spawners in the mainstem Snake River annually" (NMFS, 1995). The Bevan Team specifically did not address spawning/rearing areas in the lower mainstems of major tributaries in setting that objective - stating that "…a lack of information precludes setting escapement objectives at this time." It is likely that lower reaches in the Clearwater, Grande Ronde and Tucannon Rivers had the potential to support 500 or more spawners based on physical habitat availability. Fall chinook spawners have been observed in all three areas in recent years (Milks et. al, 2005). Preliminary information from scale sampling and pit tag experiments indicates that natural production of fall chinook in the lower Clearwater may exhibit a complex life history pattern including overwintering in mainstem habitat before outmigrating to the sea the following spring.

Sockeye ESU

Historical sockeye production occurred in at least five Stanley Basin lakes as well as in lake systems associated with Snake River tributaries currently cut off to anadromous access (e.g., Wallowa and Payette Lakes). Current returns of Snake River sockeye are extremely low and are limited to Redfish Lake. In previous ICTRT analyses (McClure et al. 2003, McClure et al. 2005) we have concluded that at least three lakes in the Stanley Lakes Basin historically supported independent sockeye populations (Redfish Lake, Alturas Lake and Stanley Lake).

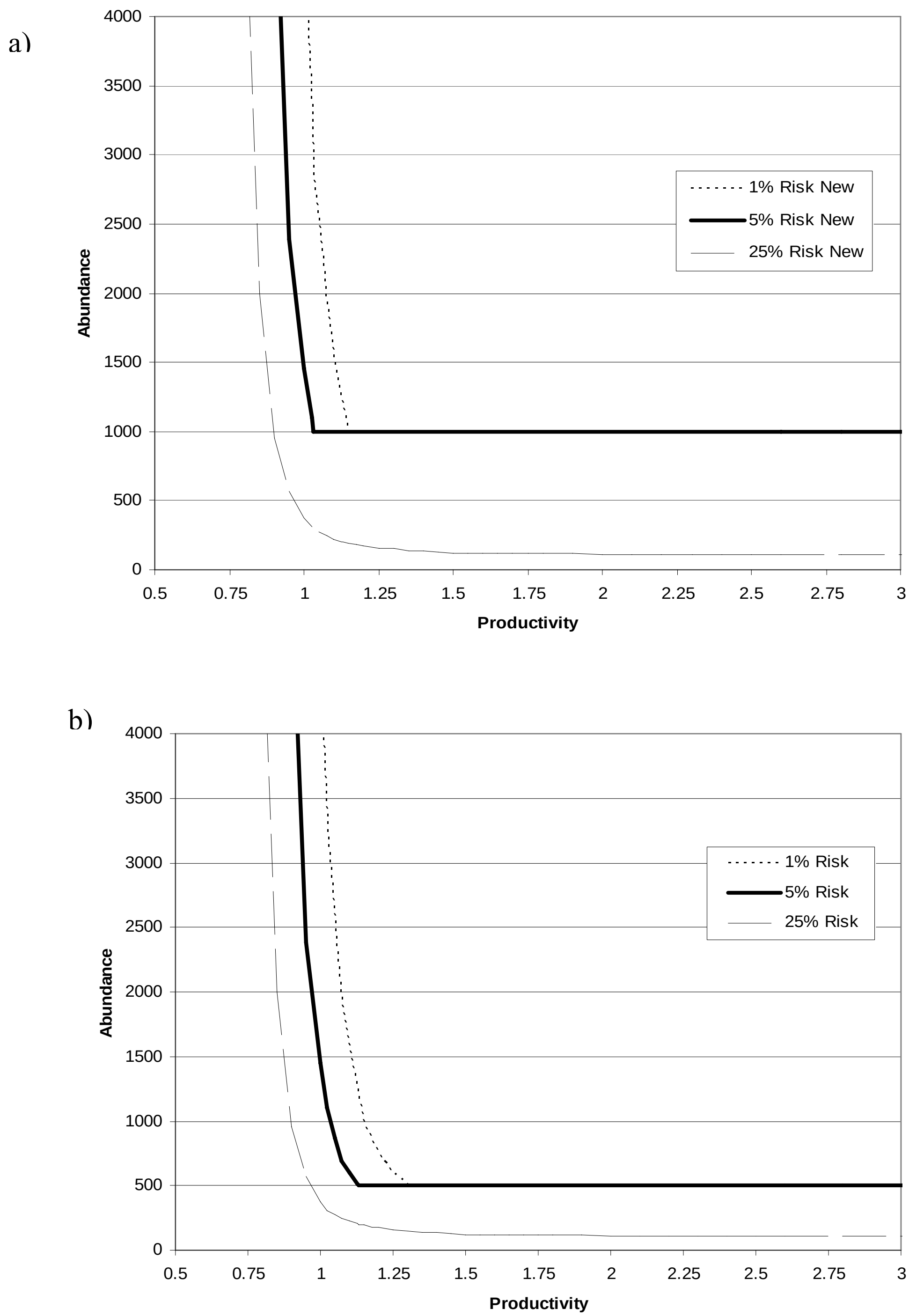
We do not have a sufficient trend data set specifically for Redfish Lake sockeye to use in generating a viability curve. As a surrogate, we used a data set for Lake Wenatchee sockeye to generate estimates of variance and autocorrelation in return rates (adjusted variance = 0.42, autocorrelation=0.41).

The approach we used to generate a viability curve requires input of a representative adult age structure. Bjornn et al. (1968) identified similarities between Redfish Lake and Wenatchee Lake sockeye runs in age at length and the predominance of 2 year ocean residency in returning adults. We generated an estimate of average age structure for Redfish Lake sockeye using smolt age sampling data summarized in Bjornn et al. (1968) as a starting point. Redfish Lake sockeye smolts outmigrated after one or two years residency in freshwater. The proportions varied considerably across brood years, The median proportion age 1 migrants for the 1954 to 1963 year classes was 0.60. Information cited in Bjornn et al. (1968) indicates that almost all returning adults had spent 2 years at sea. Based on these estimates, we assumed that the average age composition of returning adult Redfish Lake sockeye was 60% 4 year olds and 40% 5 year olds.

We generated two sets of curves for application to potential Stanley Lake Basin sockeye populations (Figure A-18). We developed relative population size category designations for Columbia Basin lake systems based on relative surface areas (Appendix B). The Stanley Basin Lakes are relatively small compared to other lake systems that historically supported sockeye production in the Columbia Basin. Stanley Lake is assigned to the smallest size category along with Pettit and Yellowbelly Lakes. Redfish Lake and Alturas Lake fall into the next size category – Intermediate. We adapted the recovery abundance levels recommended by the Snake River Recovery Team (Bevan, et al. 1994) as minimum abundance thresholds. We set the minimum spawning abundance threshold at 1,000 for the Redfish and Alturas Lake populations (intermediate category), and at 500 for populations in the smallest historical size category (e.g., Stanley Lake).

These estimates should be viewed as interim long-term abundance/productivity objectives for Stanley Basin sockeye populations. Returns of Snake River sockeye have been at extremely low levels for a considerable period of time. Initial efforts aimed at recovery will likely put a high priority on increasing survival of juvenile outmigrants and adult returns to levels that will allow for rebuilding. Information on juvenile productivity and on specific year to year variations in Redfish Lake brood year return rates gathered during the initial phase of recovery efforts should allow for future refinements of the interim ICTRT Snake River sockeye abundance and productivity criteria.

Figure A-18a-b. Viability curves for application to Snake River sockeye lake populations. A) Redfish Lake and Alturas Lake (Intermediate); B) small lake populations (Stanley Lake). Age structure used was 60% age 4 and 40% age 5 adult returns. Adjusted variance (variance unexplained by autocorrelation) and autocorrelation parameters (derived from Lake Wenatchee data) were 0.42 and 0.41, respectively.



Updating Viability Curves

The ICTRT developed a set of viability curves based analyses of trend data sets available (or applicable) for each ESU as of December, 2005. We recommend that these curves be periodically reviewed and updated as appropriate. At a minimum, additional return year data will become available for each series. Techniques for estimating escapements for populations may be improved, leading to revisions in the estimates used in generating the viability curves. Additional data series may become available. The ICTRT recommends that viability curves should be comprehensively reviewed and updated every 5 years, in phase with periodic population status updates. The choice of a five year interval reflects a balance between ensuring that recovery targets are based on updated information and avoiding frequent, minor changes to criteria resulting from yearly updates. We recommend using a test to ensure that updates leading to relatively substantial changes in viability curves are incorporated, while minimizing the need to update all analyses dependent upon viability curves in response to relatively minor shifts.

The viability curves for Interior Columbia ESUs reflect specific estimates of variance and autocorrelation in return rates. Estimates of these two parameters can be updated as escapement estimates become available for each additional year, or as a result of revisions to run reconstruction methods. We developed the following test to highlight when changes in those estimates are sufficiently large to warrant updating viability curves used in recovery planning.

1) Generate an updated version of the 5% viability curve for the Basic size population grouping of the ESU under consideration.

2) Compare the resulting curve to the current (without data updates) versions of the 1%, 5% and 25% risk curves for the ESU at abundance levels between 500 and 1000.

    a. To facilitate the comparison, calculate intermediate risk curves for intermediate levels (3%, 15%) using for the current (without data updates) data.

3) Adopt the updated viability curve parameters IF:

    a. The updated version of the 5% curve exceeds the curve associated with a 3% risk of extinction (previous data set), or

    b. The 5% curve falls below the curve associated with a 15% risk (previous data set)

Sensitivity Analyses
Viability Curve Input Parameters

The input parameters driving the form of ESU specific viability curves are each subject to substantial process and measurement uncertainties. We evaluated the sensitivity of viability curves to variations in the input values for variance and autocorrelation in intrinsic productivity and in average age structure. We used the average values calculated from Snake River spring/summer chinook population data sets as a baseline for the sensitivity assessment. We structured the sensitivity analysis to allow for comparisons of the impact of proportional variations across the three input parameters. We generated a range of values for each input parameter using a common set of proportional multipliers (Table A-4).

We evaluated the effects of sequentially varying each of the three input parameters on the viability curves. We generated a set of viability curve parameters corresponding to each of the three inputs. In any given set, the remaining two input parameters were maintained at the baseline level.

Table A-4. Range of input parameters used in viability curve sensitivity analyses.

Proportion of Input Value	Viability Curve Parameter		
	Total Variance (geomean productivity)	Autocorrelation (geomean productivity)	Age Structure (4 yr old proportion)
2.00 x	2.48	--	--
1.50 x	1.86	0.80	.85
1.25 x	1.55	0.65	.71
1.00 x	**1.24**	**0.53**	**.57**
0.75 x	0.93	0.40	.42
0.50 x	0.62	0.27	.28
0.25 x	0.31	0.14	.14

The QET and RFT were held at baseline levels for the variance, autocorrelation and age structure sensitivity runs. In a separate analysis, we evaluated the impact on viability curves of incorporating different values for QET and for RFT.

We used consistent metrics for contrasting the results of the sensitivity runs to facilitate comparisons. We expressed the results of the individual parameter analyses in terms of the minimum productivity associated with threshold abundance levels for the four size categories of spring/summer chinook populations (i.e., 500, 750, 1000 and 2000).

Variance and Autocorrelation

Projected viability curves are particularly sensitive to input parameters for variance and autocorrelation in productivity (spawner to spawner return rate).

The effect of total variance on the minimum productivity at threshold abundance levels is most pronounced for the basic population category (Table A-5a). Holding all other input parameters at their average values and setting the total variance at 0.75 and 1.25 times the average level used in generating spring/summer chinook viability curves changes the minimum productivity at threshold abundance by -24% and +47%, respectively. The relative change at higher abundance levels is dampened, but follows the same pattern.

Proportionally varying the level of autocorrelation input (holding other input variables constant) also had a substantial effect on the projected viability curve (Table A-5b). The average autocorrelation for the Snake River Spring/Summer Chinook ESU populations was 0.53. Increasing the input value for autocorrelation by 25% or more resulted in substantial increases in the required productivity at threshold abundance levels.

Table A-5a. Estimated productivities as a function of **total variance in productivity** (spawner to spawner return rates). Results at Snake River Spring/Summer Chinook ESU average total variance are in bold type. Results are presented as productivities corresponding to minimum equilibrium escapement levels (5% risk) by population size category (basic, intermediate, large and extra large). All other viability curve input parameters are held at recent geomeans for Snake River spring summer ESU populations.

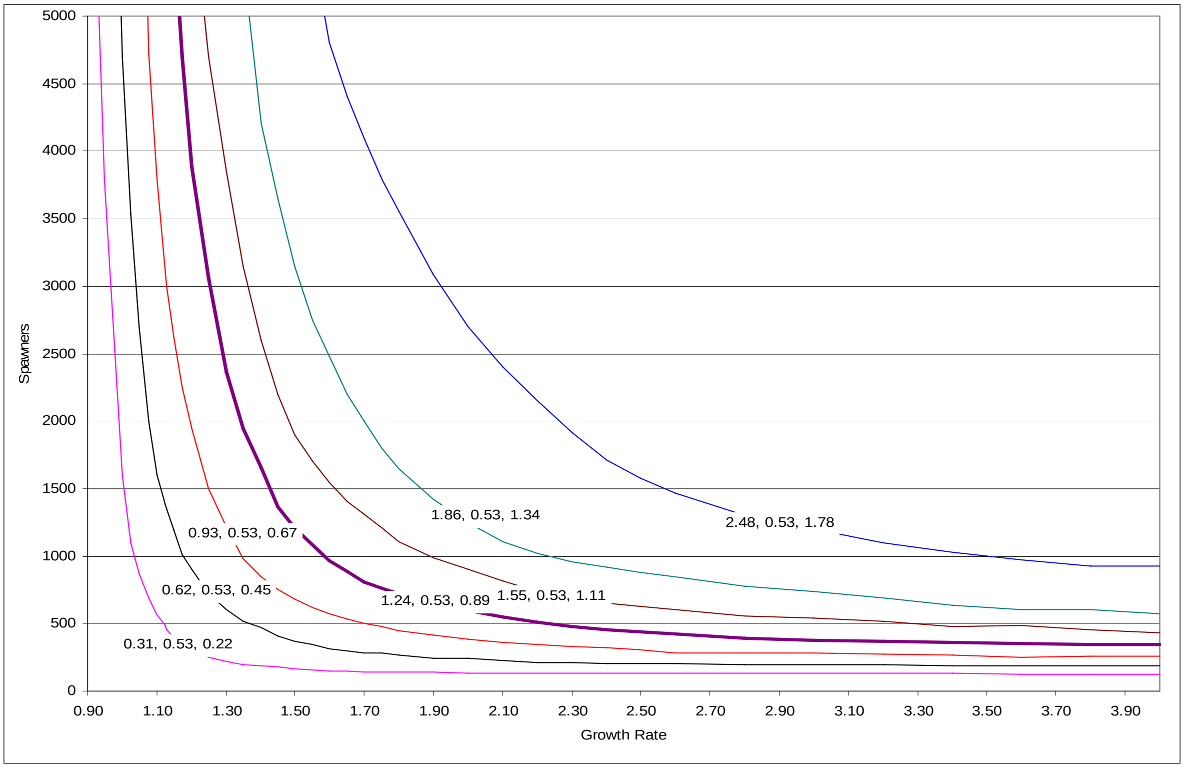
Total Variance (spawner to spawner return rate)	Minimum Population Size			
	500	750	1000	2000
0.31	1.11	1.08	1.04	0.98
0.62	1.34	1.25	1.17	1.08
0.93	1.69	1.44	1.38	1.19
1.24	**2.21**	**1.76**	**1.56**	**1.34**
1.55	3.25	2.22	1.82	1.48
1.86	5.60	2.88	2.22	1.70
2.48	6.00+	5.00+	3.42	2.22

Table A-5b. Estimated productivities as a function of **autocorrelation in productivity** (spawner to spawner return rates). Results at Snake River Spring/Summer Chinook ESU average total variance are in bold type.

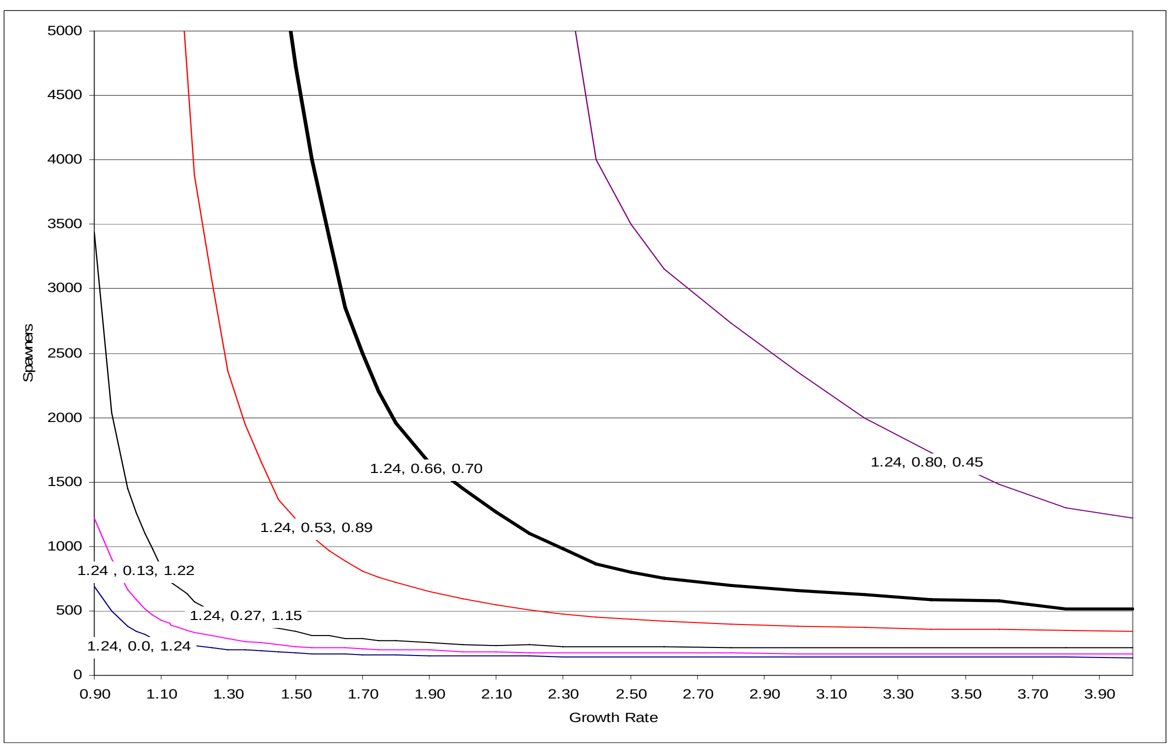
Autocorrelation (Spawner to spawner return rate)	Minimum Population Size			
	500	750	1000	2000
0	0.95	0.88	0.85	n/a
0.13	1.06	0.98	0.93	0.85
0.27	1.25	1.13	1.07	0.96
0.53	**2.21**	**1.76**	**1.56**	**1.34**
0.66	4.10	2.60	2.25	1.78
0.80	5.00+	5.00+	4.30	3.20

Figure A-19a-b. Sensitivity of Snake River Spring/Summer Chinook viability curve to a) a range of total variance input values above and below the ESU average (1.24 total variance, 0.89 after adjustment for autocorrelation, autocorrelation fixed at ESU average level of 0.53); and b) autocorrelation input values.

a)



b)



Age structure

Adult spawning returns for Interior Columbia stream type chinook populations are predominated by 4 and 5 year old fish. In many years a relatively small component of 3 year old returns are present, virtually all of these fish are males. A small percentage of mature adults return at age 6. For the purposes of this analysis we included those fish as age 5 returns. The viability curves derived for Snake River Spring/Summer Chinook population categories incorporate an average age composition for the ESU (0.57 age 4, 0.43 age 5 returns). We systematically varied age composition (Table A-4) and evaluated the sensitivity of projected viability curves, holding other input parameters at the recent average values used in constructing the viability curves for this ESU presented in the ICTRT viability report.

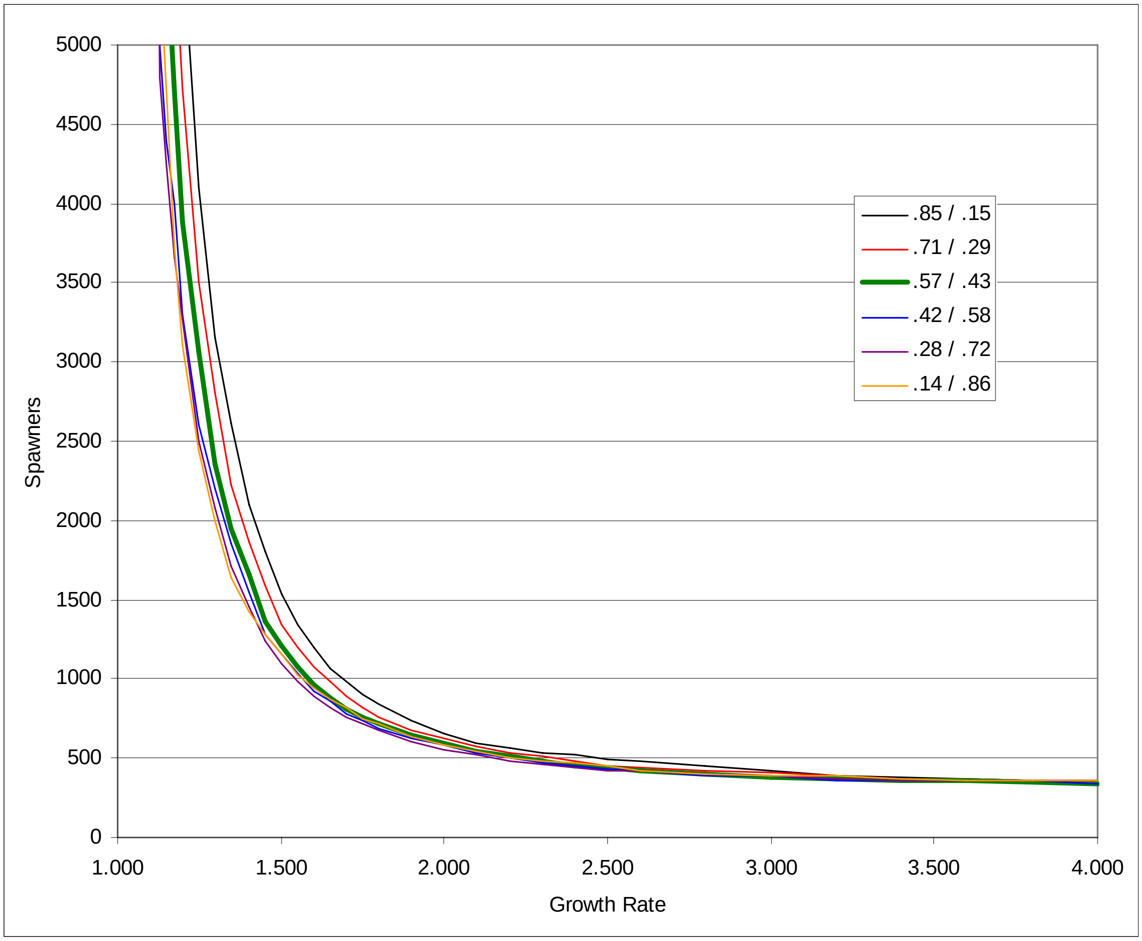


Figure A-20. Sensitivity of a Snake River Spring/Summer Chinook 5% risk viability curve to a range of age structures above and below the ESU average (0.57 age 4; 0.43 age 5). Total variance and autocorrelation were maintained at ESU average levels of 1.24 and 0.53, respectively. A QET of 50 adult spawners per year for four years was used.

Variations on the average age composition resulted in relatively small changes to projected viability curves (Figure A-20, Table A-6). The relative change in the productivity associated with minimum abundance was greatest for the basic population size category. Reducing the proportion 4 year olds by half decreased the required productivity by approximately 10%, while increasing the proportion by 1.5 resulted in a relative increase of approximately 10% . Changes for other size categories were generally lower (+9% to -4% at the limits of the range in input values).

Table A-6. Estimated productivities as a function of **average age structure** (results at ESU average age structure in bold type). Results are presented as productivities corresponding to minimum equilibrium escapement levels by population size category (basic, intermediate, large and extra large). All other viability curve input parameters are held at recent geomeans for Snake River Spring/Summer Chinook ESU populations.

Age Structure (Prop. 4/Prop. 5 year old spawners)	Minimum Population Size			
	500	750	1000	2000
0.85 /0.15	2.45	1.78	1.72	1.43
0.71 / 0.29	2.29	1.77	1.68	1.39
0.57 / 0.43	**2.21**	**1.76**	**1.56**	**1.34**
0.42 / 0.58	2.20	1.73	1.54	1.34
0.28 / 0.72	2.16	1.71	1.53	1.31
0.14 / 0.86	2.13	1.70	1.51	1.30

Quasi-Extinction Threshold (QET)

The ICTRT viability curves were generated using a QET value of 50 spawners per year for a four year period. We evaluated the sensitivity of the projected viability curves to a range of QET input values. The range of QET values tested included an alternative corresponding to explicit extinction (less than 2 spawners per year), multiples of the 50 spawners per year value used by the ICTRT, and three larger values (150, 200 and 250 spawners per year) corresponding to thresholds applied to populations classified as Medium and Large in LC-WTRT analyses for application to Lower Columbia ESUs (LCWTRT, 2006 viability draft ref).

We generated viability curves (5% risk over 100 years) for each QET value (Figure A-21). To facilitate comparisons, we expressed the results as minimum productivities associated with meeting threshold population size values for Interior Columbia basin Snake River Spring/Summer Chinook populations (Table A-7).

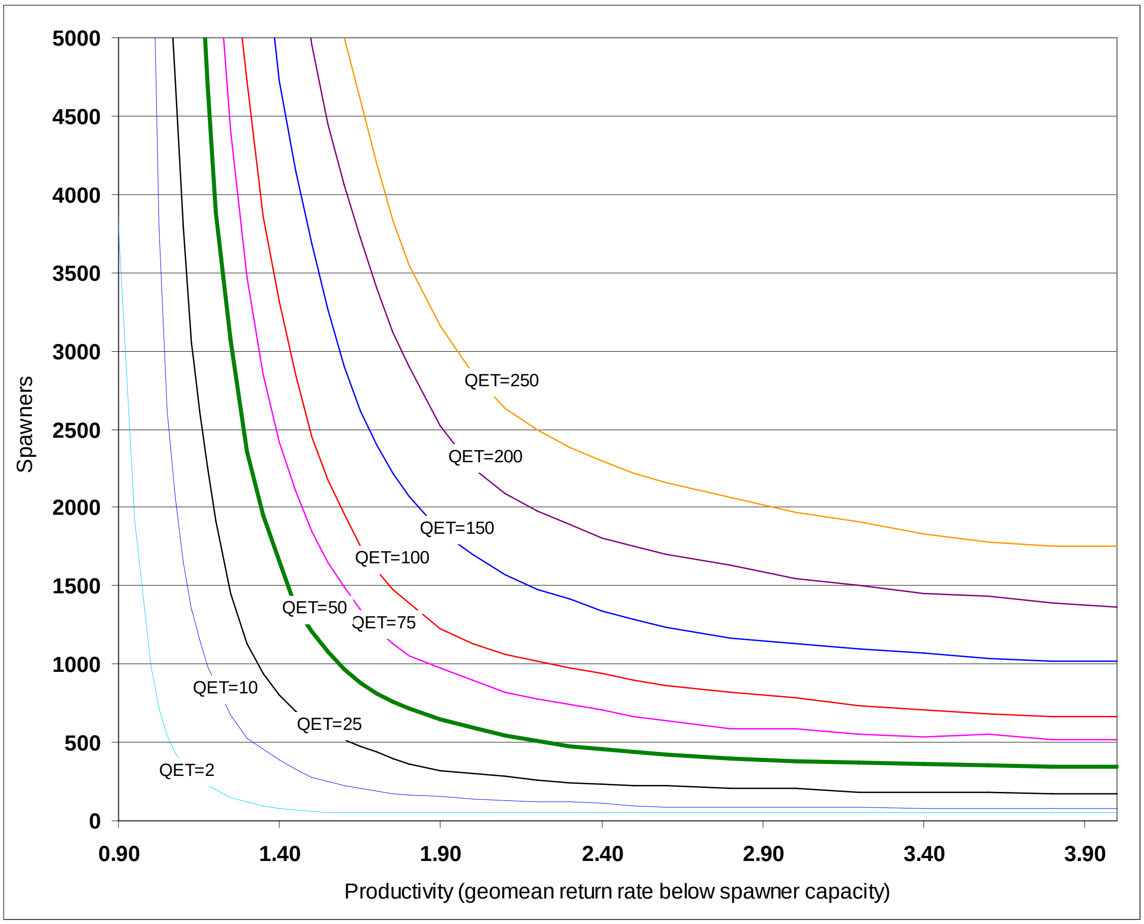


Figure A-21. Sensitivity of Snake River Spring/Summer Chinook viability curve to a range of QET values above and below the level of 50 spawners/year adopted by the ICTRT (1.24 total variance, 0.89 after adjustment for autocorrelation). The RFT was set at 10 in the model runs for QET values of 10 or greater. The RFT was set at 2 for runs in which the QET was 2.

Table A-7. Sensitivity analysis of **QET input values**. Estimated productivities at minimum equilibrium escapement levels corresponding to alternative population size classes. QET values greater than 100 were included to facilitate comparison to LC-WTRT analyses for larger population categories. In this analysis, the reproductive failure threshold (RFT) was set to 10 spawners except for the QET of 2 (RFT was also set to 2 in this case).

QET Threshold Escapement	Minimum Population Size			
	500	750	1000	2000
2	1.05	1.03	1.00	0.95
10	1.36	1.22	1.18	1.08
25	1.60	1.42	1.34	1.19
50	**2.21**	**1.76**	**1.56**	**1.34**
100	10.00+	3.50	2.27	1.58
150	10.00+	10.00+	4.20	1.87
200	10.00+	10.00+	10.00+	2.20
250	10.00+	10.00+	10.00+	2.90

The productivities required to meet or exceed the viability curves at minimum average population abundance levels were substantially affected by the choice of a QET value. Increasing the QET value from 50 to 100 roughly doubled the required productivity at threshold abundance levels for the two smallest population size categories. The productivities at threshold abundance levels were increased by approximately 45% for the large category and by 18% for the extra large population size category.

Setting the QET at 25 spawners per year reduced productivities associated with population size category minimum abundance levels by 28% (basic) to 11%(very large).

Setting the QET at 2 fish reduced the projected average productivities at population size category abundance thresholds by 29% to 52% relative to requirements associated with the QET of 50 spawners per year. The relative reductions in required productivity are greatest for populations within the basic size grouping.

We conducted two additional analyses of the sensitivity of model risk projections to the choice of a QFT value. One set of tests evaluated the impact of the choice of a QET input on the proportion of relatively low escapements in projected model runs. The second test evaluated the relative impact of incorporating 'the wrong' QET value.

A major rationale in setting the QET at 50 spawners per year in establishing viability curves for Interior Columbia ESU populations was the uncertainty associated with productivities at escapements that were below levels in the historical record. Model runs incorporating lower QETs would be expected to project higher proportions of annual escapements below 50 spawners, even when the productivity and abundance levels incorporated into the runs reflect projected extinction risk of 5% or less. We compared model runs incorporating the range of QET values summarized in Table A-6 to evaluate the impact of QET on the expected proportion of relatively low escapements. The RFT was set at 10 fish for all of the QET values except the lowest value (QET = 2). In that case, the RFT was also set at 2 spawners. Each of the model runs incorporated input parameters corresponding to a 5% risk of extinction in 100 years for the particular QET being tested in the run. We calculated the expected proportion of annual spawning escapements at relatively low escapement levels as a function of QET (Table A-8) .

The number of 100 year simulation runs out of 1000 with a relatively high proportion of escapements below 50 spawners increased as QET was decreased. The proportion of relatively low escapements increased substantially when the QET was lowered from 10 to 2 spawners.

Table A-8. Comparison of the incidence of projected annual spawning escapements below 50 spawners per year as a function of QET. Equilibrium abundance was set at 500 spawners. Productivity was set at the level corresponding to a projected risk of 5% over 100 years. RFT used in model runs in parentheses.

Assigned QET (RFT)	Number of annual spawning escapements less than 50 (in 100 year model runs)		
	10 or more	20 or more	30 or more
2 (2)	46.6%	27.7%	19.4%
10 (10)	20.6	8.4	5.3
25 (10)	12.1%	3.8%	2.2%
50 (10)	1.7%	0.1%	0.0%

We evaluated the potential effects of setting the QET value at a particular level when the 'true' QET is at a different value. We ran these model runs with an equilibrium population abundance of 500 spawners. We ran a set of model projections for each combination of assumed and underlying actual QET values. For each combination, the productivity associated with a 5% risk for the assumed QET was used as input. We ran the model with the actual QET to determine the projected risk associated with the input productivity. The results are summarized in Table A-9. For example, the projected risk of extinction in 100 years if the actual QET value is 50 but the assumed value is 2 would be 47%. Conversely, if the actual QET value is 2 and the assumed QET is 10, the projected 100 year risk is 0.2% (Table A-9).

Table A-9. Comparison of projected risks across productivities associated with 5% risk at for a basic population with an equilibrium population size of 500. Rows: assigned QET (productivity in parentheses). Columns correspond to actual QET incorporated into model runs. Entries are the projected extinction risk for the combination of assigned and modeled QET. Reproductive failure threshold (RFT) was set to 10 spawners except when QET = 2 (RFT was set to 2 in these cases).

Assigned QET (prod @ threshold)	Effective (Actual) QET			
	2	10	25	50
2 (1.05)	**5%**	19%	30%	47%
10 (1.36)	0.2%	**5%**	11%	22%
25 (1.60)	0.1%	2%	**5%**	14%
50 (2.21)	0.0%	0.2%	1%	**5%**

Reproductive Failure Threshold (RFT)

The stochastic population viability model used to generate viability curves incorporates a reproductive failure threshold (RFT). For each particular set of input parameters being tested, the model generates a minimum of 1,000 simulations of population performance projected over 100 or more years. Each of the 100 year simulation runs is structured as a series of annual time steps, using the age structure input values to distribute production from a particular brood year across future return years. If spawning escapement in any particular year falls below the RFT value, production from that brood year is set to zero. As a result, there would be no contributions from that particular brood year to future return years. We evaluated four alternative RFT values ranging from 2 to 50 spawners, holding other input values at the levels used in generating the viability curves (table A-10).

Table A-10. Sensitivity analysis of **RFT input values**. Estimated productivities needed to achieve 5% risk at minimum equilibrium escapement levels corresponding to alternative population size classes. The QET was held at 50 spawners for four consecutive years in all runs.

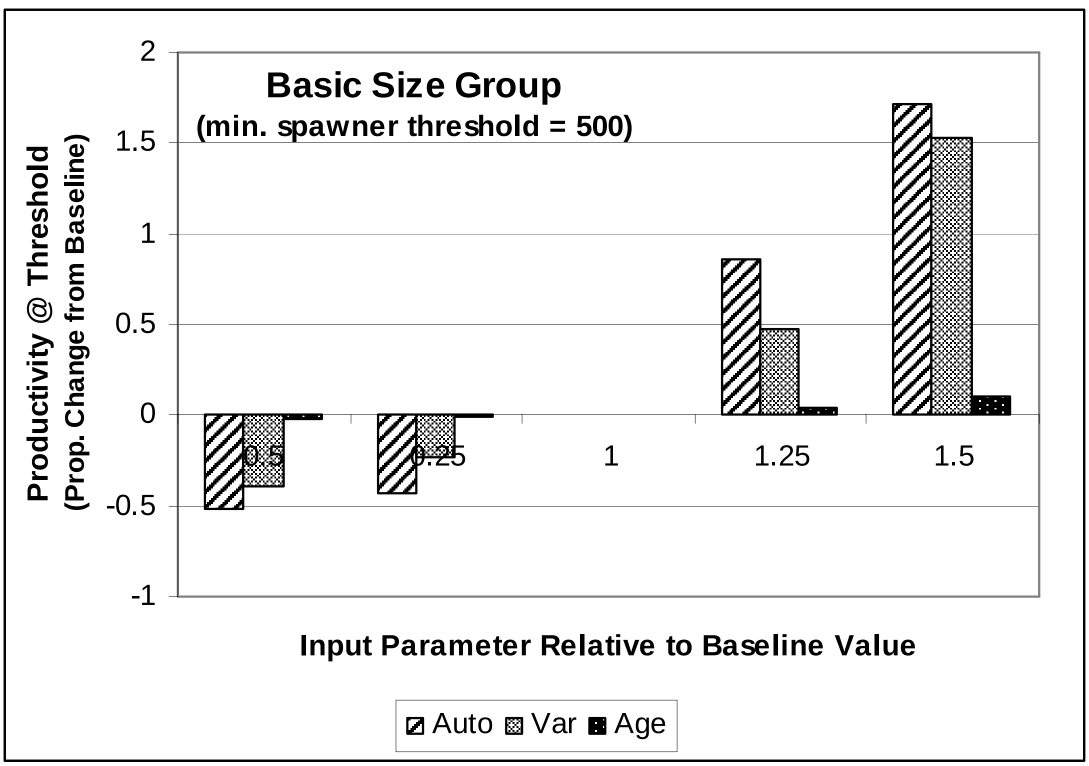
RFT Escapement	Minimum Population Size			
	500	750	1000	2000
2	2.10	1.73	1.54	1.32
10	**2.21**	**1.76**	**1.56**	**1.34**
25	2.28	1.79	1.60	1.36
50	2.43	1.93	1.69	1.41

Relative Sensitivity

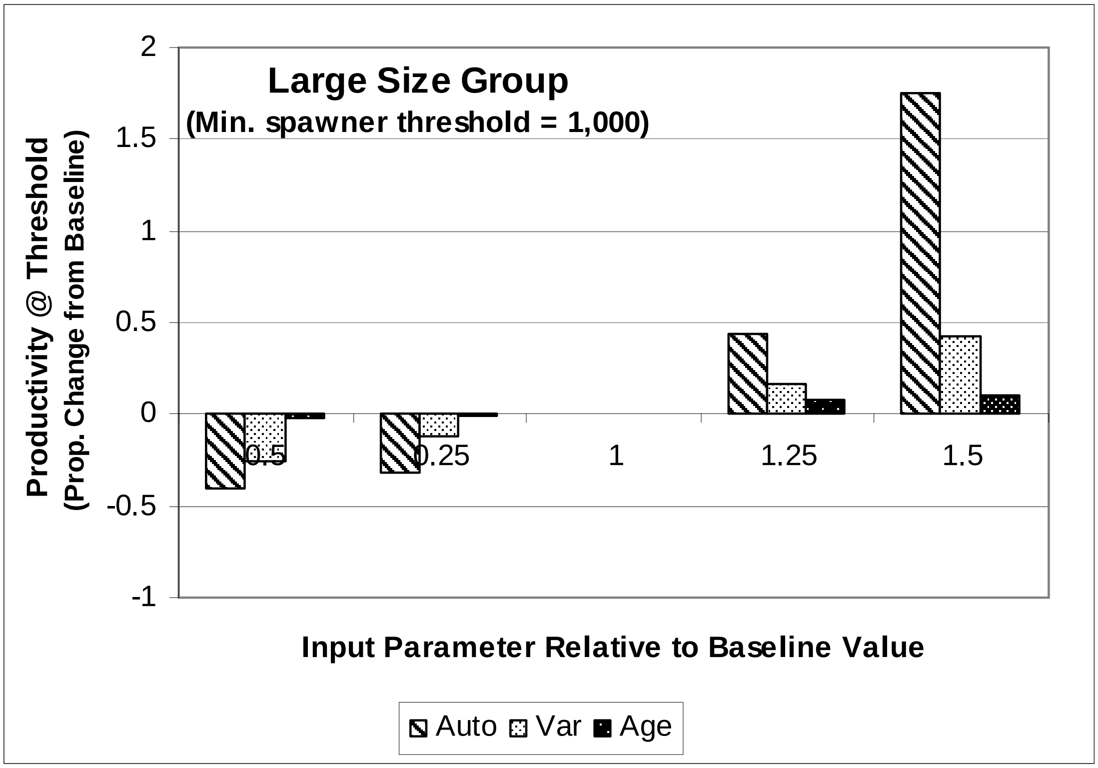
We compared the relative sensitivity of projected viability curves to proportional changes in the three population specific input factors. We used the estimated productivities at equilibrium spawning level (500 and 1,000) corresponding to a projected risk level of 5% extinction in 100 years as a standard index of the viability curves. The projected curves were most sensitive to alternative values of autocorrelation in annual productivities (Figure 22). Variations in the input value for total productivity also generated substantial changes in the relative position of the viability curve. Variations in average age structure did not substantially impact the position of the curve in these examples. Viability curves with a minimum abundance threshold for application to relatively small populations (i.e., the Basic size category) were more sensitive to modest variations in the input parameters for autocorrelation and total variance than curves with a Large population size threshold (1,000). Increasing the autocorrelation input value above 0.80 resulted in a substantial increase in the projected productivities for the large size category as well.

Figure A-22a-b. Relative effects of proportional variations in population input parameters on estimated productivity associated with a projected 5% risk of extinction at equilibrium population size of 500 spawners. Initial input values were geomean estimates for Snake River spring/summer chinook populations. Each parameter was varied from by a standard set of proportions (see Table A-4).

a)



b)


Large Size Group
(Min. spawner threshold = 1,000)
Productivity @ Threshold
(Prop. Change from Baseline)
2
1.5
1
0.5
0
-0.5
-1
0.5
0.25
1
1.25
1.5
Input Parameter Relative to Baseline Value
Auto
Var
Age

Literature Cited

Bevan, D., J. Harville, P. Bergman, T. Bjornn, J. Crutchfield, P. Klingeman and J. Litchfield. 1994. Snake River Recovery Team: final recommendations to National Marine Fisheries Service. May 1994.

Burgner, R.L. 1991. The life history of sockeye salmon (Oncorhynchus nerka). In: C. Groot and L. Margolis (eds.), Life history of Pacific salmon. p. 3 -117. Univ. of British Columbia Press. Vancouver, B.C.

Bjornn, T.C., D.R. Craddock, D.R. Corley. 1968 chk Migration and survival of Redfish Lake, Idaho sockeye salmon, *Oncorhynchus nerka*. Trans. Amer. Fish. Soc. :360-373.

Holmes, E.J. 2001. Estimating risks in declining populations with poor data. Proc. Natl. Acad. Sci. 98(9):5072-5077.

Ginzberg, L.R., L.B. Slobodkin, K. Johnson and A.G. Bindman. 1982. Quasi-extinction probabilities as a measure of impact on population growth. Risk Analysis 2:171-181.

McElhany, P., T. Backman, C. Busack, S. Heppell, S. Kolmes, A. Maule, J. Myers, D. Rawding, D. Shively, A. Steel, C. Steward & T. Whitesel. 2003. Draft Willamette/Lower Columbia Pacific Salmonid Viability Criteria. March, 2003

McElhany, P. Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C. and Bjorkstedt, E.P. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. Technical Memorandum NMFS-NWFSC-42. United States Department of Commerce, National Oceanic and Atmospheric Administration. Seattle, WA.

Milks, D., Varney, M, Schuck, M. and Sands, N. J. 2005. Lyons Ferry hatchery evaluation fall chinook salmon annual report: 2001 and 2002. Rept. to USFWS Lower Snake River Compensation Plan Office. April 2005. 100 p.

Morris, W.F. and D. F. Doak. 2002. Quantitative Conservation Biology: Theory and practice of population viability analysis. Sinauer Assoc. Inc. U.S.A. 480 p.

National Marine Fisheries Service. (1995). Proposed Recovery Plan for Snake River Salmon. U.S. Dept. of Commerce. March, 1995.

Wichmann, MC, K. Johst, M. Schwager, B. Blasius & F. Jeltsch. 2005 Extinction risk, coloured noise and the scaling of variance. Theor. Pop. Biol. 68: 29-40